U.S. Department of the Interior
U.S. Geological Survey

Simulation of Flow in the Upper North Coast Limestone Aquifer, Manatí-Vega Baja Area, Puerto Rico

Prepared in cooperation with the
PUERTO RICO DEPARTMENT OF NATURAL AND ENVIRONMENTAL RESOURCES
and the PUERTO RICO INDUSTRIAL DEVELOPMENT CORPORATION

Water-Resources Investigation Report 00-4266

USGS
science for a changing world

Cover photograph

Western portion of Laguna Tortuguero looking south. Photograph taken by Gregory S. Cherry, February 22, 2001.

U.S. Department of the Interior
U.S. Geological Survey

Simulation of Flow in the Upper North Coast Limestone Aquifer, Manatí-Vega Baja Area, Puerto Rico

By Gregory S. Cherry

Water-Resources Investigations Report 00-4266

In cooperation with the

PUERTO RICO DEPARTMENT OF NATURAL AND ENVIRONMENTAL RESOURCES
and the PUERTO RICO INDUSTRIAL DEVELOPMENT CORPORATION

San Juan, Puerto Rico: 2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
GSA Center, Suite 400-15
651 Federal Drive
Guaynabo, Puerto Rico 00965

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, WATER-QUALITY UNIT, ACRONYMS, and TRANSLATIONS

Multiply	By	To obtain
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.0929	meter squared per day
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
million gallons per day (Mgal/d)	0.02832	million liters per day
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (°C \times 1.8) + 32$$

Abbreviated water-quality unit used in this report:

mg/L milligrams per liter

Acronyms used in this report

NCCD North Coast Climatic Division
PRASA Puerto Rico Aqueduct and Sewer Authority
PRDNER Puerto Rico Department of Natural and Environmental Resources
USGS U.S. Geological Survey

Translations

Spanish	English
caño	channel or drainage ditch
de	of
grande	grand or large
el, los, la, las	the
lago	lake
laguna	lagoon
municipio	generally equivalent to county
norte	north
quebrada	stream or creek
río	river
sur	south

Simulation of Flow in the Upper North Coast Limestone Aquifer, Manatí-Vega Baja Area, Puerto Rico

By Gregory S. Cherry

Abstract

A two-dimensional computer ground-water model was constructed of the Manatí-Vega Baja area to improve the understanding of the unconfined upper aquifer within the North Coast Province of Puerto Rico. The modeled area covers approximately 79 square miles within the municipios of Manatí and Vega Baja and small portions of Vega Alta and Barceloneta.

Steady-state two-dimensional ground-water simulations were correlated to conditions prior to construction of the Laguna Tortuguero outlet channel in 1940 and calibrated to the observed potentiometric surface in March 1995. At the regional scale, the unconfined Upper North Coast Limestone aquifer is a diffuse ground-water flow system through the Aguada and Aymamón limestone units. The calibrated model input parameters for aquifer recharge varied from 2 inches per year in coastal areas to 18 inches per year in the upland areas south of Manatí and Vega Baja. The calibrated transmissivity values ranged from less than 500 feet squared per day in the upland areas near the southern boundary to 70,000 feet squared per day in the areas west of Vega Baja. Increased ground-water withdrawals from 1.0 cubic foot per second for 1940 conditions to 26.3 cubic feet per second in 1995, has reduced the natural ground-water discharge to springs and wetland areas, and induced additional recharge from the rivers. The most important regional drainage feature is Laguna Tortuguero, which is the major ground-water discharge body for the upper aquifer, and has a drainage area of approximately 17 square miles. The discharge to the sea from Laguna Tortuguero through the outlet channel has been measured on a bi-monthly basis since 1974. The outflow represents a combination of ground- and surface-water discharge over the drainage area.

Hydrologic conditions, prior to construction of the Laguna Tortuguero outlet channel in 1943, can be considered natural conditions with minimal ground-water pumpage (1.0 cubic foot per second), and heads in the lagoon were 2.4 feet higher. The model was calibrated to March 1995 conditions during a dry period of minimal aquifer recharge and relatively constant water levels in the upper aquifer. For the steady-state 1995 model simulation, however, ground-water pumpage had been increased to 26.3 cubic foot per second, due to increased demand for public water supply, the heads at 0.9 feet, and the outflow to the sea at Laguna Tortuguero had been lowered considerably.

Simulated ground-water inflow for 1940 hydrologic conditions included 35.9 cubic feet per second from areal recharge, contributions from streamflow along the southern boundary of 1.6 cubic feet per second, and streamflow infiltration to the upper aquifer of 4.2 cubic feet per second. Simulated ground-water outflow for 1940 hydrologic conditions are discharge to springs of 17.4 cubic feet per second, total ground-water withdrawals of 1.0 cubic feet per second, and aquifer contribution to streamflow or wetland areas of 23.4 cubic feet per second.

Simulated ground-water inflow for hydrologic conditions of March 1995 included contributions from streamflow along the southern boundary of 1.6 cubic feet per second, areal recharge of 35.9 cubic feet per second, and streamflow infiltration to the upper aquifer of 11 cubic feet per second. Simulated ground-water outflow for hydrologic conditions of March 1995 are ground-water withdrawals of 26.3 cubic feet per second, discharge from springs of 7.3 cubic feet per second, and aquifer contribution to streamflow or wetland areas of 14.9 cubic feet per second. The overall ground-water budget increased from 41.8 cubic feet per second for 1940 conditions to 48.6 cubic feet per second for the hydrologic conditions of March 1995. The increase in ground-water budget is a direct result of increased ground-water withdrawals, which induced greater streamflow infiltration.

Simulated ground-water flux to Laguna Tortuguero for 1940 conditions was 11 cubic feet per second, which dropped to 5.2 cubic feet per second in March 1995, as the result of extensive ground-water pumping. Base flow measurements at the outlet of Laguna Tortuguero at station number 50038200, from 1995 to the present, averaged 6.9 cubic feet per second. Earlier measurements, taken from 1974 to 1980, which can be considered base flow or flow during relatively dry periods, averaged 16.2 cubic feet per second.

A transient simulation was conducted for a period ending in 1995, using the construction of the Laguna Tortuguero outlet in 1943 as a reference starting point. The historical pumpage was reconstructed from available records for each stress period, while recharge rates remained relatively constant with slight changes required in the river model segment to simulate the water level for Laguna Tortuguero. The aquifer heads for the 1995 transient simulation were slightly higher than the 1995 steady-state simulation, with an average absolute deviation of 3.17 feet, compared to 3.10 feet.

Sumario

Para entender mejor el sistema hidrogeológico del acuífero superior en la provincia de la costa norte de Puerto Rico, se construyó un modelo digital bidimensional de agua subterránea para el área de Manatí-Vega Baja. El área que se presenta en este modelo cubre unas 79 millas cuadradas dentro de los municipios de Manatí y Vega Baja y pequeñas porciones de Vega Alta y Barceloneta.

Hay tres ríos principales que fluyen hacia el norte y atraviesan el área del modelo de agua subterránea: el Río Grande de Manatí, Río Cibuco y Río Indio. El acuífero no confinado de la Caliza Superior de la Costa Norte se encuentra al norte de la latitud 18 grados 25 minutos y se extiende hasta áreas de humedales rodeando la Laguna Tortuguero, donde el agua subterránea descarga a manantiales o directamente a la laguna. En la década de 1930, la red de canales y el canal de desembocadura a la Laguna Tortuguero fueron construidos para drenar las áreas de humedales para el control de la malaria y aumentar el área cultivable de la caña de azúcar.

Las simulaciones en condición de equilibrio del modelo bidimensional de agua subterránea se correlacionaron con las condiciones que existían antes de la construcción del canal de desembocadura de la Laguna Tortuguero en 1940, e inclusive fueron calibradas según la superficie potenciométrica observada en marzo de 1995. En una escala regional, el acuífero no confinado de la Caliza Superior de la Costa Norte es un sistema difuso de flujo de agua subterránea a través de unidades de caliza de Aguada y el Aymamón. Los parámetros entrados al modelo calibrado de recarga del acuífero variaron de 2 pulgadas al año en áreas costeras, a 18 pulgadas al año en las áreas elevadas al sur de Manatí y Vega Baja. Los valores de transmisividad calibrados fluctuaron entre menos de 500 pies cuadrados por día en las áreas elevadas cercanas a la frontera sureña, y 70,000 pies cuadrados en las áreas al oeste de Vega Baja. El aumento en las extracciones de agua subterránea de 1.0 pie cúbico por segundo para las condiciones en 1940, a 26.3 pies cúbicos por segundo en 1995, ha reducido la descarga natural de agua subterránea a manantiales y áreas de humedales, y ha inducido una mayor infiltración de los ríos. El drenaje de agua subterránea más importante proveniente del acuífero superior es la Laguna Tortuguero, con un área de drenaje de unas 17 millas cuadradas. La descarga de la Laguna Tortuguero hacia el mar por el canal de desembocadura ha sido medida cada dos meses desde 1974. El efluente representa una combinación de descarga de agua subterránea y superficial sobre el área de drenaje.

Las condiciones hidrológicas previas a la construcción del canal de desembocadura de la Laguna Tortuguero en 1943 pueden considerarse como promedio, con un bombeo mínimo de 1.0 pie cúbico por segundo y niveles hidrostáticos más altos, o de 3.3 pies (1.0 metro) sobre el nivel medio del mar. El modelo fue calibrado de acuerdo con las condiciones de marzo de 1995, durante un período de sequía, cuando la recarga al acuífero fue mínima. No obstante, para la simulación en equilibrio de 1995, el bombeo había sido aumentado a 26.3 pies cúbicos por segundo, debido a la creciente demanda del abasto de agua público y el nivel hidrostático, a 0.9 pie, y la descarga de agua subterránea al mar y a la Laguna Tortuguero había disminuido considerablemente.

El flujo simulado que entra al sistema de agua subterránea para 1940 consiste en una recarga aérea de 35.9 pies cúbicos por segundo, contribuciones del caudal a lo largo de la frontera sur de 1.6 pies cúbicos por segundo e infiltración del caudal al acuífero superior de 4.2 pies cúbicos por segundo. El flujo simulado de salida del sistema de agua subterránea para 1940 consiste en descarga a manantiales de 17.4 pies cúbicos por segundo, extracciones de agua subterránea de 1.0 pie cúbico por segundo y contribución al caudal de ríos o áreas de humedales de 23.4 pies cúbicos por segundo.

El flujo simulado que entra al sistema de agua subterránea para marzo de 1995 consiste en contribuciones del caudal a lo largo de la frontera sur de 1.6 pies cúbicos por segundo, una recarga aérea de 35.9 pies cúbicos por segundo e infiltración de caudal al acuífero superior de 11 pies cúbicos por segundo. El flujo simulado de salida del sistema de agua subterránea para marzo de 1995 consiste en extracciones de agua subterránea de 26.3 pies cúbicos por segundo, descarga a manantiales de 7.3 pies cúbicos por segundo y contribución al caudal o áreas de humedales de 14.9 pies cúbicos por segundo. El balance de agua subterránea aumentó de 41.8 pies cúbicos por segundo para las condiciones de 1940 a 48.6 pies cúbicos por segundo para las condiciones hidrológicas de marzo de 1995. El aumento de agua subterránea es el resultado directo de mayores extracciones de agua subterránea que indujeron una infiltración mayor de caudal.

El flujo de drenaje de agua subterránea simulado hacia el drenaje de la Laguna Tortuguero para las condiciones de 1940 fue de 11 pies cúbicos por segundo, el cual bajó a 5.2 pies cúbicos por segundo en marzo de 1995 como resultado de la explotación extensa de agua subterránea. Los aforos del caudal de base en la desembocadura de la Laguna Tortuguero en la estación número 50038200 desde 1995 hasta el presente promediaron 6.9 pies cúbicos por segundo. Otros aforos realizados desde 1974 hasta 1980, los cuales pueden considerarse como caudal de base o caudal durante períodos de relativa sequía, promediaron 16.2 pies cúbicos por segundo.

Para el período que finalizó en 1995, se realizó una simulación en condición transitoria utilizando la construcción de la desembocadura de la Laguna Tortuguero en 1943 como punto de referencia. El bombeo histórico fue reconstruido utilizando documentos disponibles de cada periodo, mientras que los índices de recarga permanecieron relativamente constantes con cambios leves requeridos en la conductancia del lecho del río utilizada para regular el flujo hacia la Laguna Tortuguero y, de esta forma, calibrar los cambios en los niveles hidrostáticos. Los niveles hidrostáticos del acuífero para la simulación transitoria de 1995 fueron un poco mayores que las de la simulación de equilibrio de 1995, con una desviación absoluta media de 3.17 pies, comparada con 3.10 pies.

INTRODUCTION

In the Río Grande de Manatí to Río Cibuco area, the unconfined upper aquifer provides 80 percent of the public water supply to the towns of Manatí and Vega Baja (fig. 1). The North Coast Limestone aquifer system consists of an upper unconfined aquifer and a lower confined aquifer. In 1995, the more productive and permeable upper aquifer provided an estimated 17 million gallons per day (Mgal/d), mostly for public water supply, with minor quantities for industrial and domestic needs. The lower confined aquifer provides substantial quantities of ground water for the water-supply needs of industrial complexes near Barceloneta and Manatí (fig. 2).

The purpose of this study was to enhance understanding of the ground-water flow system within the Manatí, Puerto Rico 7½-minute quadrangle, by developing a two-dimensional ground-water flow model to simulate flow in the upper unconfined aquifer. This report describes the hydrogeology of the Upper North Coast Limestone aquifer, model development, and simulation results. The computed steady-state model heads were compared to the potentiometric surface observed in March 1995, during the calibration process. The calibrated flow model was then used to (a) assess the historical change in the potentiometric surface and aquifer water balance resulting from the large-scale dewatering works of the early 1940's, and ground-water withdrawals since the early 1960's; (b) assess the regional effects on the upper aquifer from an anticipated reduction of ground-water withdrawals for public water-supply purposes; and (c) assess the effect of changes in land-use patterns, that are expected to enhance aquifer recharge.

Description of the Study Area

The Manatí-Vega Baja study area covers approximately 79 square miles (mi^2). The area is bordered by the Atlantic Ocean on the north and by the rugged cone karst topography to the south. The western boundary is a north-south line, just west of the Río Grande de Manatí, and the eastern boundary is a north-south line, just east of the confluence of the Río Indio and the Río Cibuco (fig. 1). The area has undergone substantial changes in land use (former agricultural land developed into urban areas) with steady population growth. Like many areas of Puerto Rico, much of the arable land in the alluvial valleys was planted in sugarcane in the first half of the 1900's. A general decline of sugarcane acreage in the upland areas commenced in the 1930's, when sugarcane production areas were converted to fruit crops (primarily pineapples). The hydrology of the study area has been modified substantially, since the late 1930's by reclamation of land for agricultural use and malaria control through dewatering of wetlands in coastal areas by a system of drainage canals. In 1943, construction of an outlet channel connecting Laguna Tortuguero to the ocean dewatered additional area by lowering the lagoon water-surface elevation. By the late 1970's, sugarcane cultivation had essentially been abandoned and land was left fallow or converted to pasture for dairy cattle. In the upland plains, the land use trend has been from agricultural to urban. Portions of the municipios of Vega Baja, Manatí, and Barceloneta are within the study area. In these municipios, population has increased from 79,271 in 1950 to 126,662 in 1996 (U.S. Census Bureau, 1998), with the highest growth rate occurring within the municipio of Vega Baja. Thus, areas formerly utilized to grow sugarcane or fruit crops have been rezoned for housing (fig. 2). This trend will probably continue with the completion of the North Coast "Superaqueduct" currently under construction. The "Superaqueduct" will increase the availability of public water supply from surface-water sources and decrease withdrawals from the upper aquifer. An increase in housing development is expected to enhance aquifer recharge, as storm water runoff from developed areas is typically conveyed to the sub-surface by construction of injection wells.

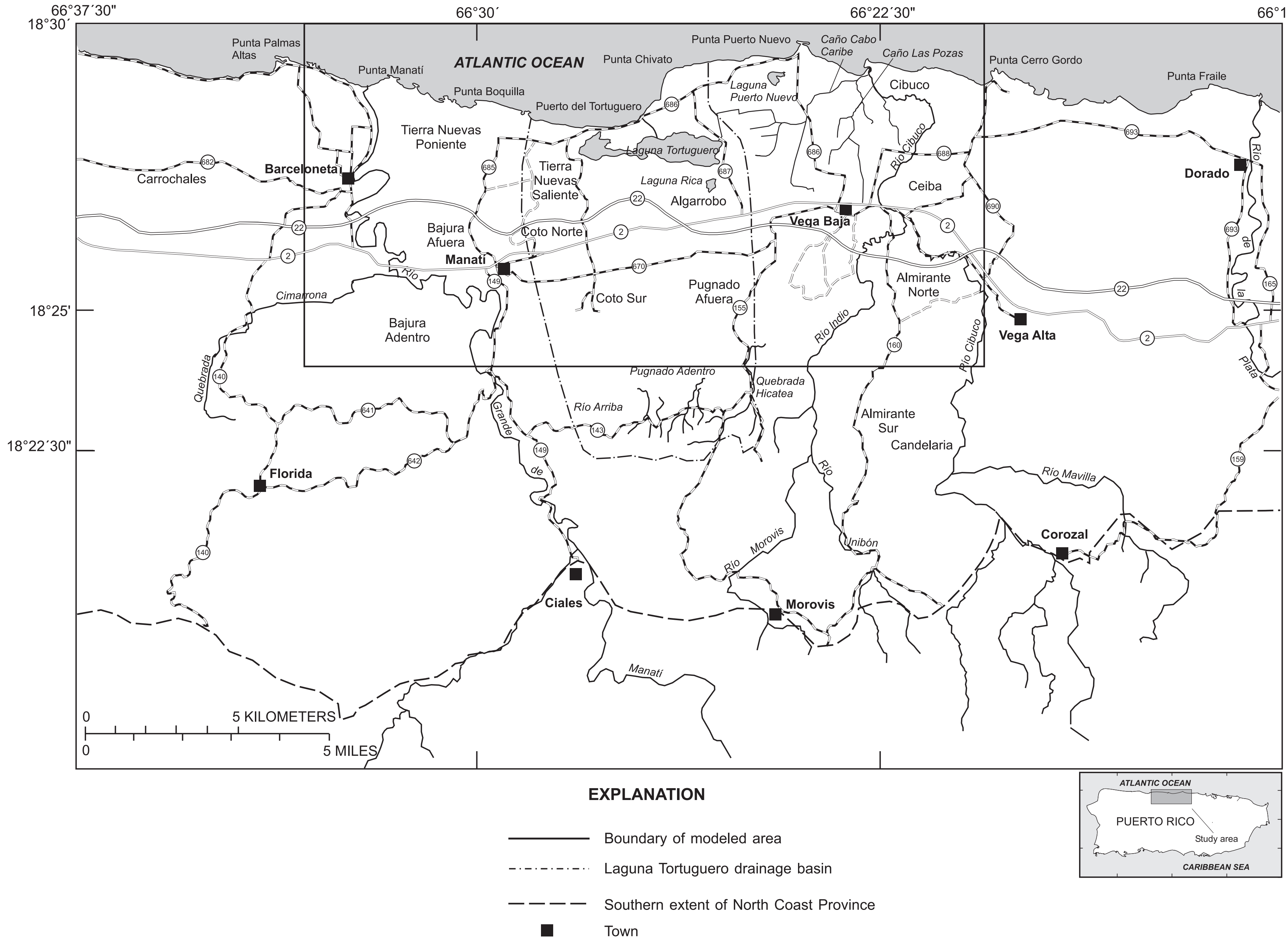


Figure 1. Location of the Manatí-Vega Baja study area and important hydrologic features, North Coast Province, Puerto Rico.

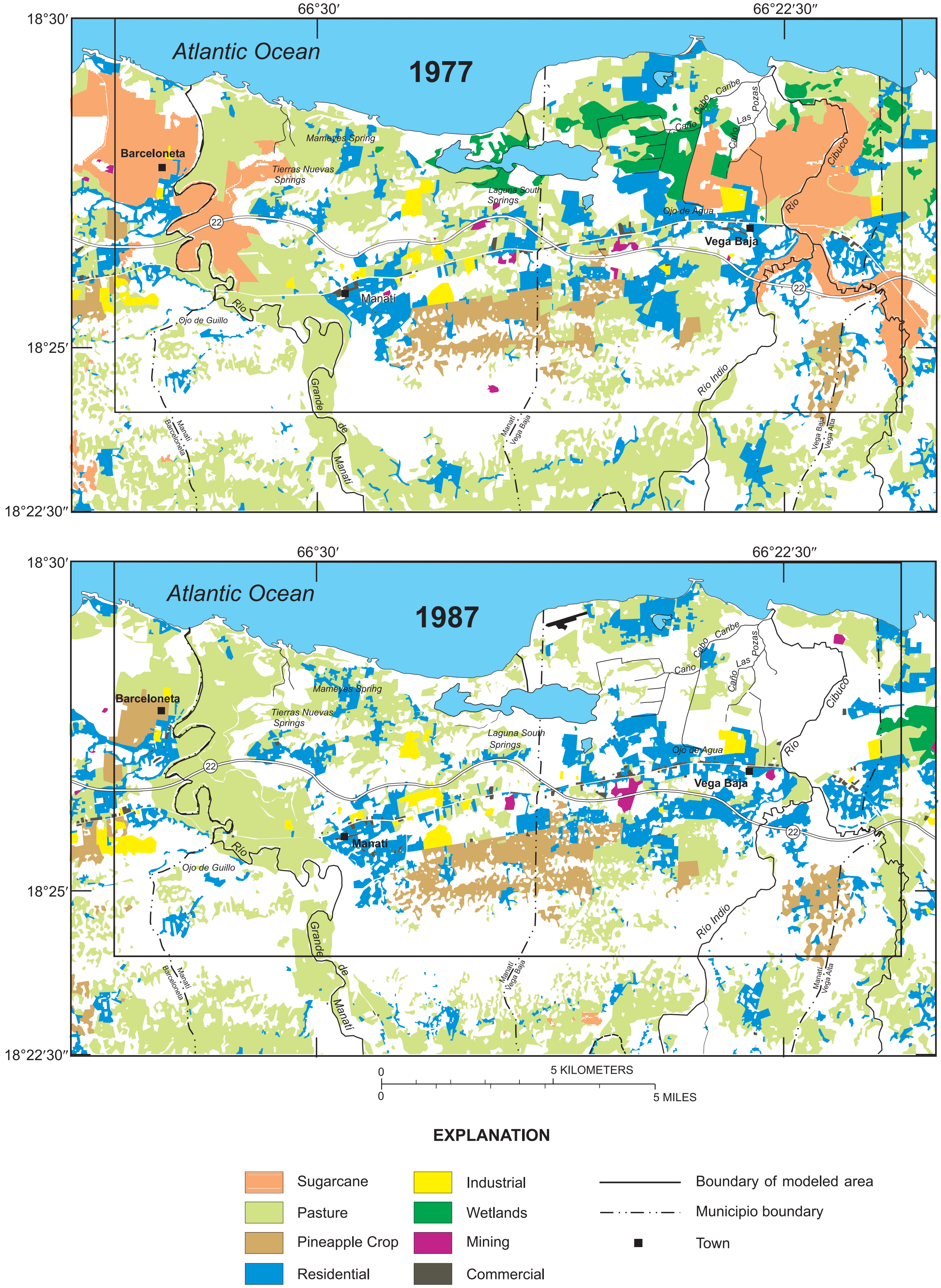


Figure 2. Selected land uses in 1977 and 1987 in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

The Manatí quadrangle lies within the North Coast Climatic Division (NCCD) of Puerto Rico, as classified by the U.S. National Weather Service (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1982). The NCCD is characterized by nearly constant trade winds from the northeast, that maintain mean monthly temperatures to within 3 degrees Celsius (°C) of an annual mean temperature of about 25.5 °C. Average annual rainfall in the study area ranges from less than 60 inches (in.) near the coast to 70 inches in the karst terrain near the southern boundary (fig. 3). Long-term records from National Weather Service rainfall stations in the study area show a relative dry season from December to April, and a wet period from May to November, associated with the hurricane season. The mean monthly rainfall records indicate that May is the wettest month, followed closely by November; February and March are the driest months. Since 1899, 72 tropical storms or hurricanes have passed within 90 miles of Puerto Rico, with 20 making landfall on the island (Gillette and others, 1996). These storms produce torrential rains over parts of the island; a 10- inch rainfall within a 24-hour period has a return frequency of approximately 50 years.

History of Water Use

Ground-water withdrawals in the upper aquifer have historically and primarily been for public water-supply purposes. A detailed analysis of Puerto Rico's public water-supply sources in 1959 indicated withdrawals from the Puerto Rico Aqueduct and Sewer Authority (PRASA) wells located within the municipios of Manatí and Vega Baja were about 1.1 Mgal/d, and that the major springs were important contributors to the water-supply system (Arnow and Crooks, 1960). Withdrawals from the PRASA wells remained essentially unchanged through the year 1969, when ground-water withdrawals were assessed in the Laguna Tortuguero ground-water basin and estimated to be 1.95 Mgal/d (3.0 cubic feet per second (ft^3/s), Bennett and Giusti, 1972). More detailed data on the development of the aquifer as a public water-supply source were compiled from the PRASA yearly operations summary reports, which are available by region from 1982 to 1995. In addition, the Water Franchise Division of the Puerto Rico Department of Natural and Environmental Resources (PRDNER) maintains detailed records of the withdrawal rates for industrial wells in the area since 1974.

Historical ground-water use for the study area is summarized in figure 4. In the Manatí 7½-minute quadrangle area, ground-water withdrawals from the upper aquifer in March 1995 were estimated as follows: 14.7 Mgal/d for public water-supply purposes, 1.7 Mgal/d for industrial self-supplied use, and 0.5 Mgal/d for agricultural use, for a total of 16.9 Mgal/d (26.1 ft^3/s) (Conde-Costas and Rodríguez, 1997). Ground-water withdrawals however, may have reached a maximum 19.4 Mgal/d (30.0 ft^3/s) in 1984, when several irrigation wells with a withdrawal rate of about 3.0 Mgal/d were used for rice cultivation (Gómez-Gómez and Torres-Sierra, 1988) in the Río Cibuco valley (wells 32, 33, 35, and 38; fig. 4). By about 1985, the irrigation wells had ceased operation, and between 1985 and 1989 several public water-supply wells in Barrios Coto Norte and Coto Sur of Manatí were closed because of contamination by organic solvents including methylene chloride (at Coto Norte) and nitrates (at Coto Sur) (Conde-Costas and Gómez-Gómez, 1999).

The only public water-supply source from surface water is a filtration plant located along Río Indio in Barrio La Trocha of Vega Baja. This public water-supply filtration plant produced an average of 1.3 Mgal/d in 1995, up from 1.0 Mgal/d in previous years (Molina-Rivera, 1998). Also contributing approximately 0.6 Mgal/d in 1995 for public water supply to the municipio of Vega Baja is a surface-water filtration plant located south of the study area with its source being the Río Unibón, a tributary of the Río Indio (refer to fig. 1 for locations). Completion of the "Superaqueduct" will increase surface-water deliveries and allow selected public-supply wells to be placed on stand-by status (fig. 4).

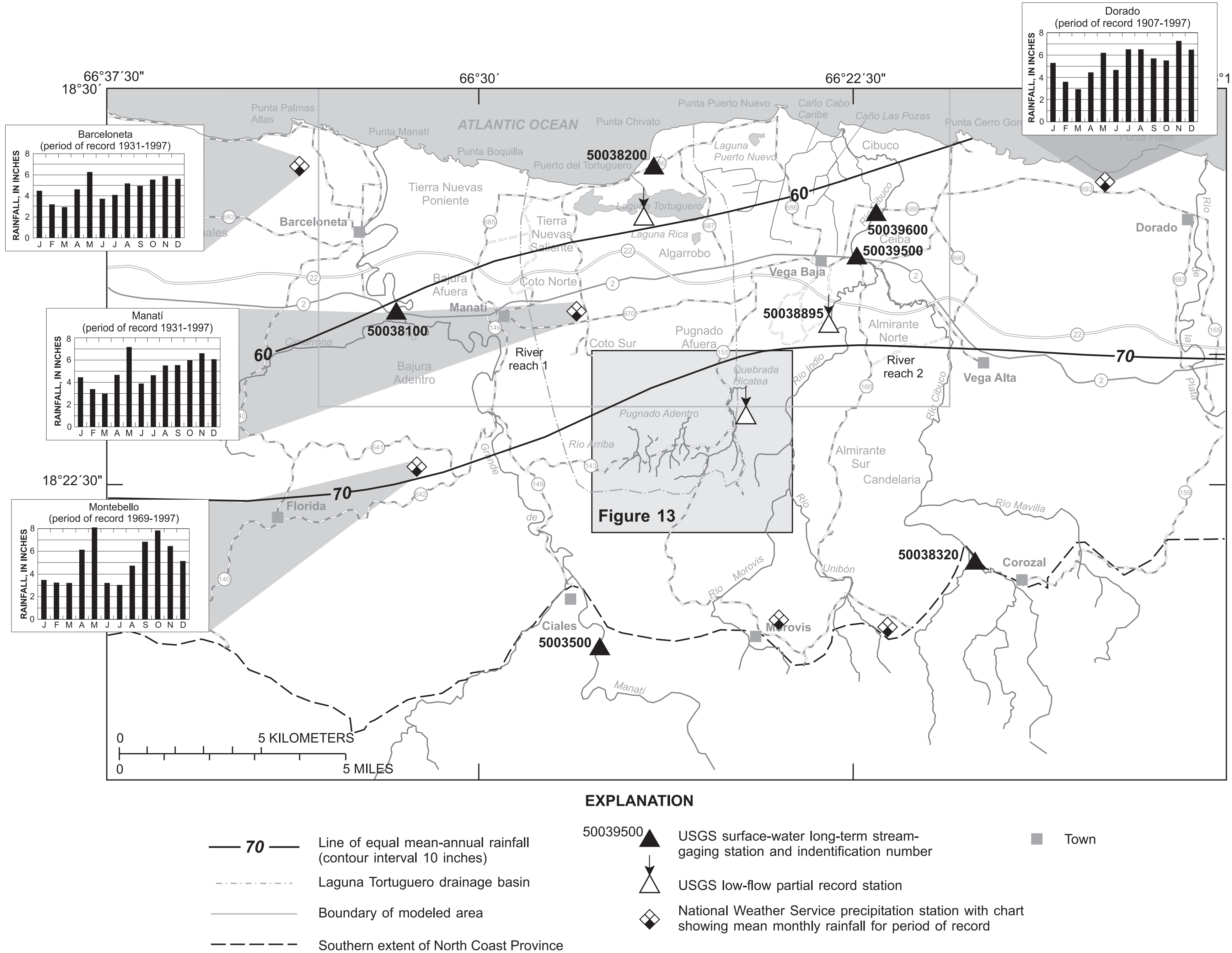


Figure 3. Average annual rainfall distribution (modified from Colón, 1983) and location of stream-gaging and precipitation stations in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

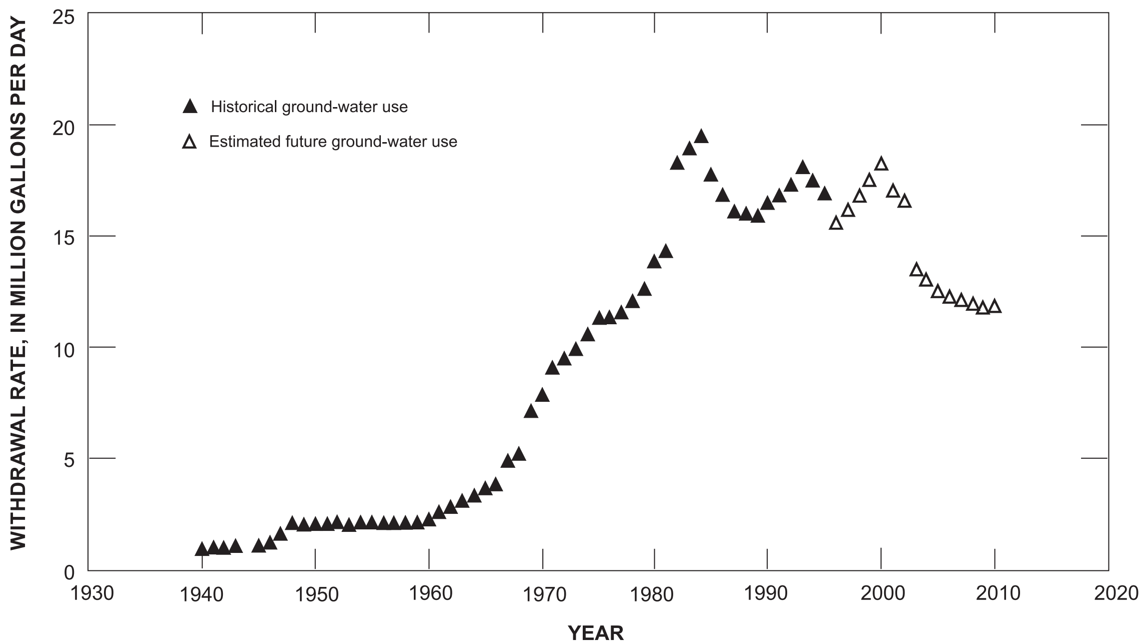


Figure 4. Historical and projected future use of ground water in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

Acknowledgments

A special thanks to the landowners who provided access along several segments of Quebrada Hicatea. The information provided by these individuals proved useful in gaining an understanding of the system. Fernando Gómez-Gómez and Sigfredo Torres-González, of the U.S. Geological Survey (USGS) Caribbean District, provided helpful feedback for understanding the ground-water system and management of the many MODFLOW files. Ronald Richards of the Caribbean District, assisted the author with seepage runs along various reaches of the Río Grande de Manatí and Río Indio. Francisco Maldonado of the Caribbean District, provided assistance with the figures.

HYDROGEOLOGIC SETTING

Within the study area, the North Coast Limestone aquifer system consists of two aquifers (fig. 5). An upper unconfined aquifer is separated from a lower confined aquifer by a confining unit. The highly permeable upper aquifer provides the majority of water used for public supply and the lower aquifer is an important source of water for industrial complexes located near the towns of Barceloneta and Manatí. The confining unit is discontinuous west of the study area, grading into more permeable limestone units that are part of the lower aquifer. To the east, the confining unit grades into more permeable limestone units that are considered to be part of the unconfined upper aquifer. The locations of wells used to define the upper and lower aquifers and confining unit are shown in figure 6. These sites are described in table 1.

Geologic Setting

Tertiary limestones within the North Coast Province generally strike to the west and dip gently to the north from 6 to 7 degrees near the contact with the volcanic rocks south of the study area, and from about 1 to 2 degrees near the coast (Monroe, 1980). These rocks, grouped into six formations, include in ascending order: the middle Oligocene San Sebastián Formation, the late Oligocene Lares Limestone, the Oligocene and Miocene Cibao Formation, the Miocene Aguada and Aymamón Limestones, and the lower Miocene Camuy Formation (fig. 5). Alluvial deposits occur in the river valleys of the Río Grande de Manatí and the Río Cibuco, with a sequence of "blanket sands" overlying limestones in upland areas (fig. 7).

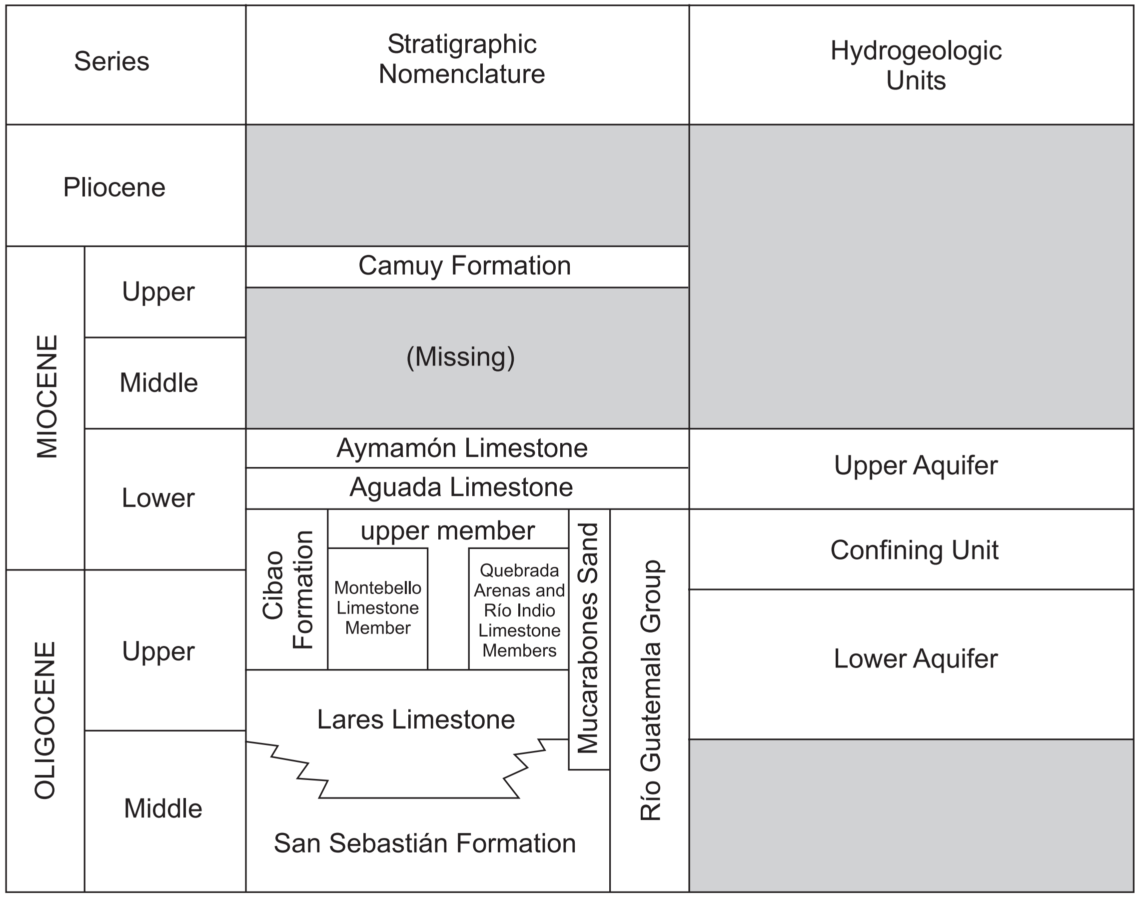


Figure 5. Stratigraphic nomenclature of the middle Tertiary sequence and hydrogeologic units of the North Coast Limestone aquifer system, Puerto Rico. Stratigraphic nomenclature modified from Monroe (1980). Geologic nomenclature of Monroe (1980), adopted by Rodríguez-Martínez (1995) in his description of the hydrogeologic framework of the North Coast Province of Puerto Rico, is used for the present report.

Rocks comprising the basal part of the Tertiary rock sequence in the North Coast Province, namely the San Sabastián Formation, the Lares Limestone, Mucarabones Sand, and Cibao Formation were defined by Zapp and others (1948) as the Río Guatamala Group. The San Sabastián Formation represents an initial interval of clastic deposition followed by a period when terrestrial material was absent and the relatively pure Lares Limestone was deposited. The Lares Limestone grades laterally into the Mucarabones Sand, just east of Corozal (Monroe, 1980). The Cibao Formation, divided into six members, represents a period dominated by clastic deposition is described as a calcareous clay, earthy limestone, or marl. Monroe (1971) mapped an outcrop of the Montebello Limestone member on the eastern side of the Río Grande de Manatí (fig. 7), but west of the Río Grande de Manatí, he subdivided the Cibao Formation into a lower member named the Montebello Limestone and an informally named upper member. Just east of the Río Grande de Manatí, the Cibao Formation grades laterally to the east and is divided into the Río Indio Limestone member and the Quebrada Arenas Limestone member. Further to the east of Río de la Plata, the lower two-thirds of the Cibao Formation grades laterally into the Mucarabones Sand (Monroe, 1980). The other two members, the Almirante Sur Sand and the Miranda Sand, are discontinuous, with most outcrops located between the Río Indio and Río Cibuco.

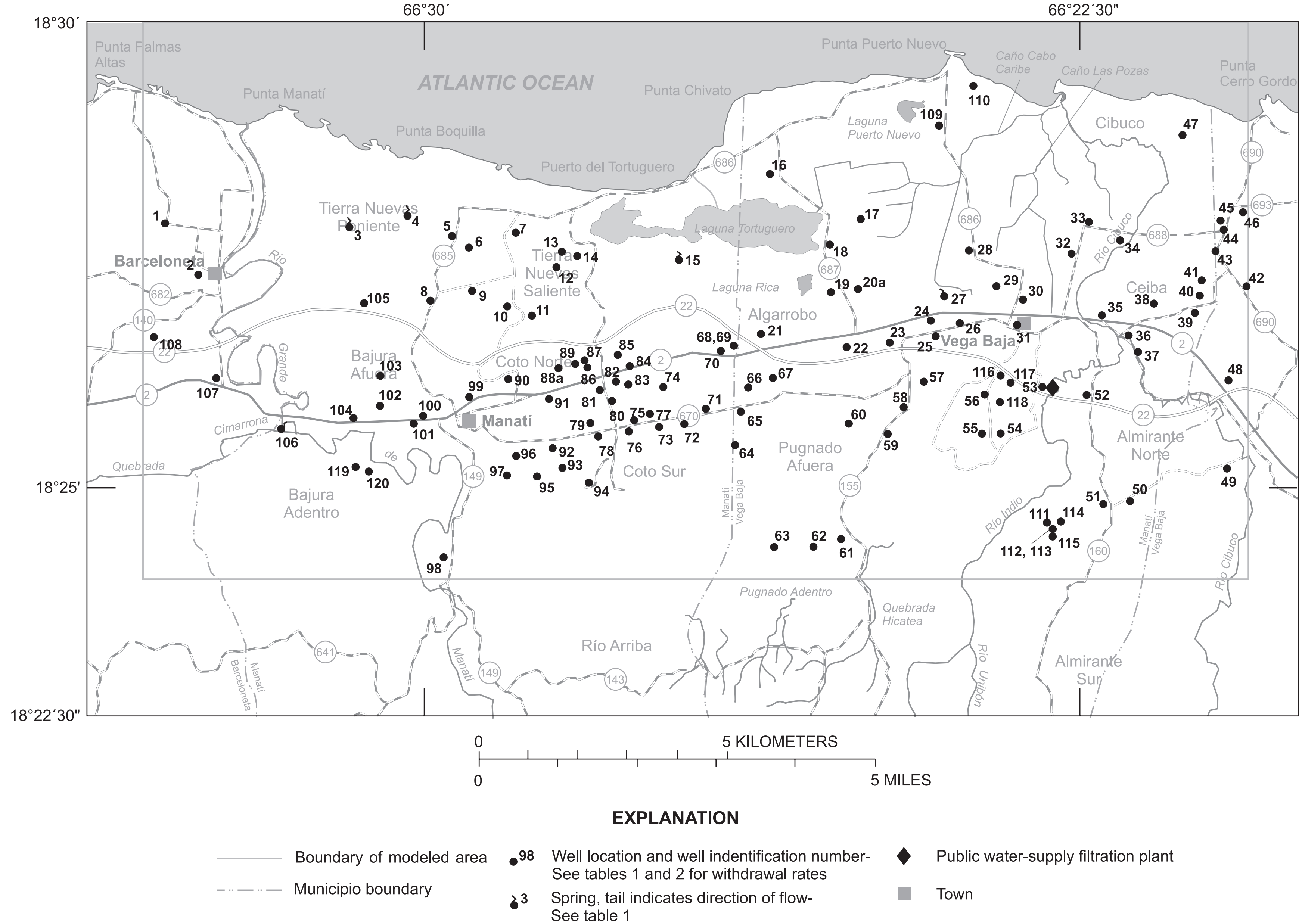


Figure 6. Location of wells, springs, and filtration plant in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

Table 1. Characteristics of well data-collection sites and location within the Manatí-Vega Baja ground-water model, North Coast Province, Puerto Rico

[X, indicates data are available]

Map number	Well name	USGS site identification number	Row	Column	Pre-development water altitude	Post-development water altitude	Lithologic data	Ground-water discharge	Transmissivity determined at well
1	Plazuela 2	1827570663256	13	2		X			
2	January Textile 1	1827250663232	16	4		X		X	X
3	Mamey Spring	1827590663041	12	15				X	
4	Tierras Nuevas	1828040663016	12	17				X	
5	Boquillas	1827520662937	13	21				X	X
6	Cubano Jacobo	1827420662927	14	22		X		X	X
7	Meléndez	1827550662856	13	25		X			
8	Cruz Rosa Rivas	1827050662952	18	20				X	X
9	Rabanos	1827140662925	17	22		X		X	X
10	Cubano Jacinto	1827010662902	18	25		X		X	
11	Dupont 3 (upper)	1826570662848	16	28		X			
12	Álvarez	1827320662828	15	28	X				
13	IAS-1	1827310662811	15	29			X		
14	Dupont 3 (lower)	1827340662809	15	30				X	
15	Laguna South Spring	1827370662707	15	35				X	
16	Martínez	1828350662558	9	42		X			
17	Cerro Guarico	1828040662457	12	48		X			X
18	NC-14	1827430662522	14	46		X	X		
19	Tortuguero TW3	1827120662517	17	46		X			
20	Tortuguero 2	1827150662458	17	48	X			X	X
20a	Tortuguero 1	1827140662502	17	48		X		X	X
21	Owens-Illinois	1826430662602	20	42		X			
22	Agregado	1826360662507	21	47				X	
23	Algarrobo	1826390662434	21	50				X	X
24	Vega Baja 2	1826520662415	19	52				X	X
25	Vega Baja 3	1826440662404	20	53		X		X	X
26	Vega Baja 4	1826460662359	20	54		X		X	
27	Ojo de Agua Spring	1826570662506	18	53				X	
28	NC-9	1827350662343	15	55		X	X		
29	China Caribe	1827170662326	17	57	X			X	X

Table 1. Characteristics of well data-collection sites and location within the Manatí-Vega Baja ground-water model, North Coast Province, Puerto Rico–Continued

Map number	Well name	USGS site identification number	Row	Column	Pre-development water altitude	Post-development water altitude	Lithologic data	Ground-water discharge	Transmissivity determined at well
30	Kirk Wing	1827040662311	18	58				X	
31	Vega Baja 1	1826480662309	20	58		X		X	
32	Rice Program 5	1827390662230	14	62		X		X	
33	Rice Program 4	1827510662219	13	63		X		X	
34	Central San Vicente	1827430662158	14	65		X		X	
35	Ceiba 1	1826560662216	19	64	X			X	X
36	Ceiba 2 Carmelita	1826400662158	20	65	X				X
37	Monserrate	1826300662150	21	66		X		X	X
38	Rice Program 3	1827060662135	18	68		X		X	
39	Sabana Hoyos 3	1826540662110	19	70		X		X	
40	Warner Lambert 2	1827070662106	18	70				X	
41	Warner Lambert 1	1827100662107	17	70		X		X	
42	Sabana Hoyos 2	1827120662037	17	73		X		X	X
43	Jardín Dorado 1	1827390662058	14	71		X			X
44	Pennock Gard. 2	1827500662049	13	72		X			
45	Cerro Gordo Nursery 1	1827560662052	13	72		X			
46	Pennock Gard. 3	1827550662042	13	73		X			
47	Finca Cibuco	1828540662119	7	69		X			X
48	Santa Rosa 2	1826100662047	23	72				X	
49	BVAW18	1825200662047	29	72		X	X		X
50	Arraiza	1824570662151	31	66				X	X
51	Almirante 2	1824520662207	31	64		X		X	X
52	Almirante 3	1825590662221	25	63		X		X	X
53	La Trocha	1826100662254	23	60		X			X
54	Pantojas	1825290662325	27	57		X		X	
55	Villa Pinares	1825320662336	27	56		X	X	X	X
56	Rosario 2	1826150662353	23	54		X			X
57	Alturas	1826160662410	23	52		X		X	
58	Pugnado Afuera 1	1825530662428	25	51		X		X	
59	Pugnado Afuera 2	1825440662438	26	50		X		X	X
60	Palo Alto 3	1825480662510	26	47		X	X		
61	Finca EM	1824280662512	34	47		X			X

Table 1. Characteristics of well data-collection sites and location within the Manatí-Vega Baja ground-water model, North Coast Province, Puerto Rico–Continued

Map number	Well name	USGS site identification number	Row	Column	Pre-development water altitude	Post-development water altitude	Lithologic data	Ground-water discharge	Transmissivity determined at well
62	E. Martínez	1824250662529	34	45		X			
63	Perica	1824260662604	34	42		X			
64	Palo Alto 1	1825310662626	27	40		X	X		
65	Pugnado 3	1825550662618	25	40		X		X	X
66	Palo Alto 2	1826140662615	23	41		X	X		
67	Sobrino	1826190662557	22	42		X		X	
68	Coto Norte 3	1826340662625	21	40		X		X	
69	NC-4	1826330662626	21	40		X	X		
70	Coto Norte 2	1826300662635	21	39				X	
71	Coto Sur 2	1825520662647	25	38		X		X	X
72	Coto Sur 7	1825480662657	26	37		X			X
73	Coto Sur 5	1825460662712	26	35		X		X	
74	Ortho Lab	1826140662709	23	35		X		X	
75	Coto Sur (WH)	1825460662730	26	33	X	X			X
76	Coto Sur 6	1825420662737	26	33		X		X	
77	Hnos Hill 2	1825510662725	25	34	X				X
78	Coto Sur 1	1825400662754	26	31		X		X	X
79	Roche	1825380662759	26	30			X	X	
80	Coto Sur 3	1825540662749	25	31	X	X		X	
81	Campo Alegre	1826080662759	24	31		X		X	X
82	Ciordia 2	1826190662742	23	32		X			
83	Eaton Labs	1826150662735	23	33		X		X	X
84	Coto Norte 1	1826230662732	22	33	X			X	X
85	Atenas	1826300662740	21	32				X	
86	Schering Plough 2	1826250662805	22	30		X		X	
87	Schering Plough 1	1826290662808	22	30		X		X	
88	Davis & Geck S	1826270662826	22	28		X		X	
88a	Davis & Geck N	1826270662824	22	28				X	
89	IAS-2	1826250662805	22	29		X	X		
90	Cordova Dávila	1826170662901	23	25		X		X	X
91	Vocacional	1826050662833	24	27		X		X	
92	Acrópolis	1825340662830	27	28		X			

Table 1. Well data-collection sites and location within the Manatí-Vega Baja ground-water model, North Coast Province, Puerto Rico–Continued

Map number	Well name	USGS site identification number	Row	Column	Pre-development water altitude	Post-development water altitude	Lithologic data	Ground-water discharge	Transmissivity determined at well
93	USGS Hill 1	1825140662821	29	29		X	X		
94	USGS Hill 2	1825060662802	30	30		X	X		
95	Finca Gil	1825150662841	29	27		X			X
96	Escal Fullery	1825300662854	28	25		X		X	X
97	Coto Sur 4	1825140662902	29	24		X		X	X
98	Monserrate Sur	1824120662949	35	20		X		X	
99	Oficina PRASA	1826050662925	24	22		X		X	X
100	Manatí 1	1825490663002	26	19		X	X	X	X
101	Manatí 2	1825590663005	26	18		X	X	X	X
102	Mckesson	1825590663025	25	16		X		X	
103	Calaf Frederico	1826210663025	23	17		X		X	X
104	Manatí 3	1825490663043	25	15		X	X		
105	Cantito La Luisa	1827100663037	16	15		X			
106	Ojo de Guillo Spring	1825410663136	26	9				X	
107	Canning 1	1826170663200	23	5		X			
108	Fortuna	1826470663308	20	1				X	
109	Jimenez Amador	1829030662405	6	53		X			X
110	Jimenez Dairy	1829240662343	4	55		X			
111	Albalabejo MW1	1824430662250	32	60		X			
112	Albalabejo MW2	1824380662246	33	61		X			
113	Albalabejo MW3	1824350662245	33	61		X			
114	Albalabejo MW4	1824430662240	32	61		X			
115	Albalabejo MW5	1824310662246	33	61		X			
116	Vega Baja Soid Waste MW1	1826140662318	23	58		X			
117	Vega Baja Solid Waste MW2	1826170662324	23	57		X			
118	Vega Baja Solid Waste MW3	1825560662323	25	57		X			
119	Bajura Adentro 1	1825200663043	29	15				X	X
120	Bajura Adentro 3	1825180663037	29	16				X	

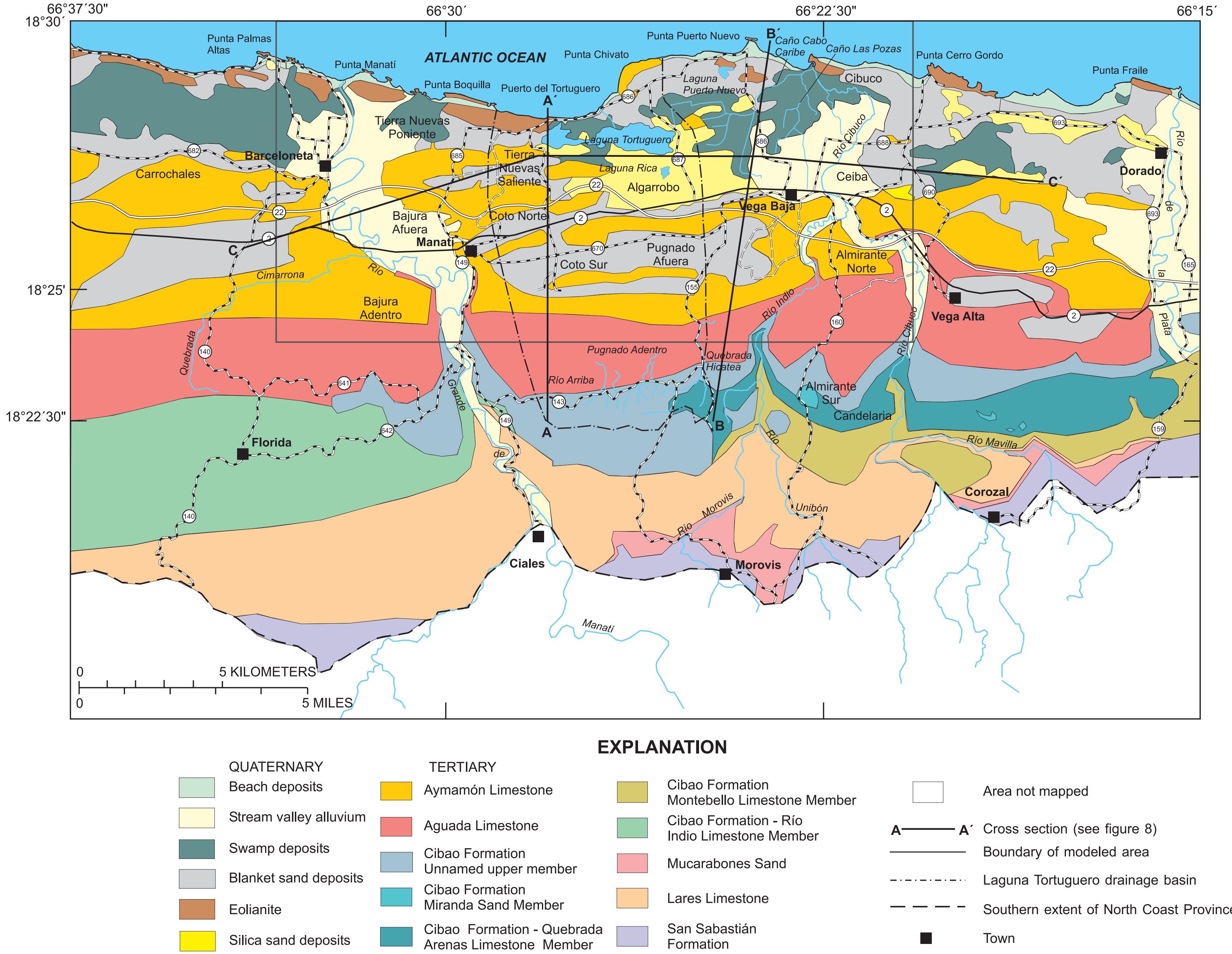


Figure 7. Generalized surficial geology of the Manatí-Vega Baja study area and location of hydrogeologic cross sections, North Coast Province, Puerto Rico. Cross sections are shown in figure 8 (modified from Monroe, 1980).

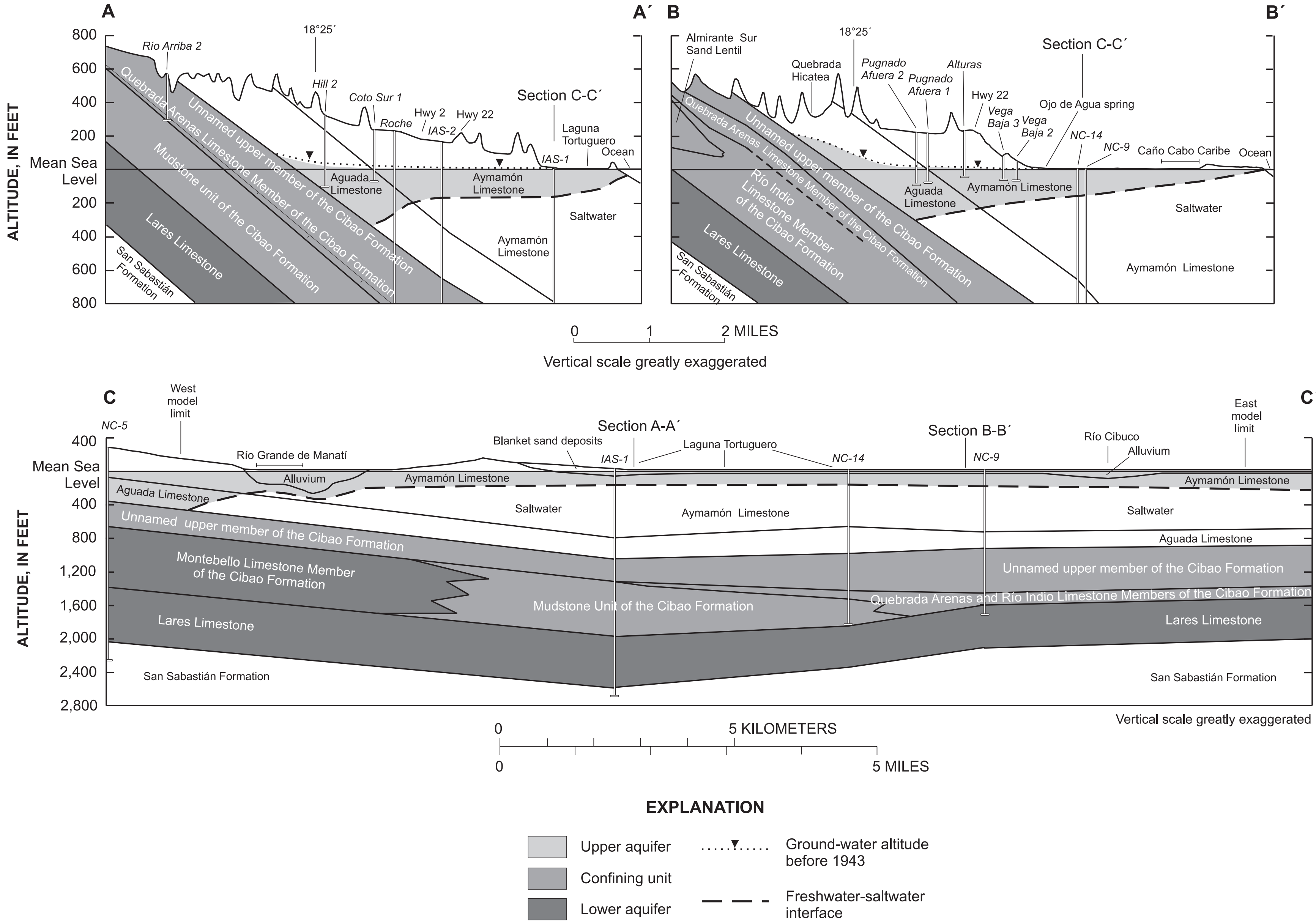


Figure 8. Generalized hydrogeologic cross sections of the Manatí-Vega Baja study area, North Coast Province, Puerto Rico. Refer to figure 7 for cross-section location.

The Aguada Limestone is considered to be transitional between the Cibao Formation and the Aymamón Limestone. The Aguada is a calcarenite and less fossiliferous than the underlying Cibao Formation (Monroe, 1980). The Aguada Limestone contains quartz grains, indicating that the rivers that formed the Cibao Formation were still active (Monroe, 1980), whereas the Aymamón Limestone is a pure massive limestone with some dolomite replacement near the coast. Where the Aymamón Limestone has not reprecipitated to form a resistant caprock or mogotal features, the unit may be a fragmented or rubbly chalk susceptible to dissolution. The dissolution of the surrounding limestones and drainage into cracks and conduits over time has produced deposits of quartz sand, clayey sand, sandy clay, and clay, called the blanket sand deposit (Briggs, 1966).

The valleys formed by the Río Grande de Manatí and the Río Cibuco are filled with alluvial deposits of mostly fine sand, silt, and clay. The area south of Laguna Tortuguero is characterized by sand deposits, having a composition of nearly 99 percent silica (Meyerhoff and Frazier, 1945). Near the coast, and locally to as much as 1,000 feet (ft) offshore, there are remnants of cemented Pleistocene eolian dunes (eolianite deposits).

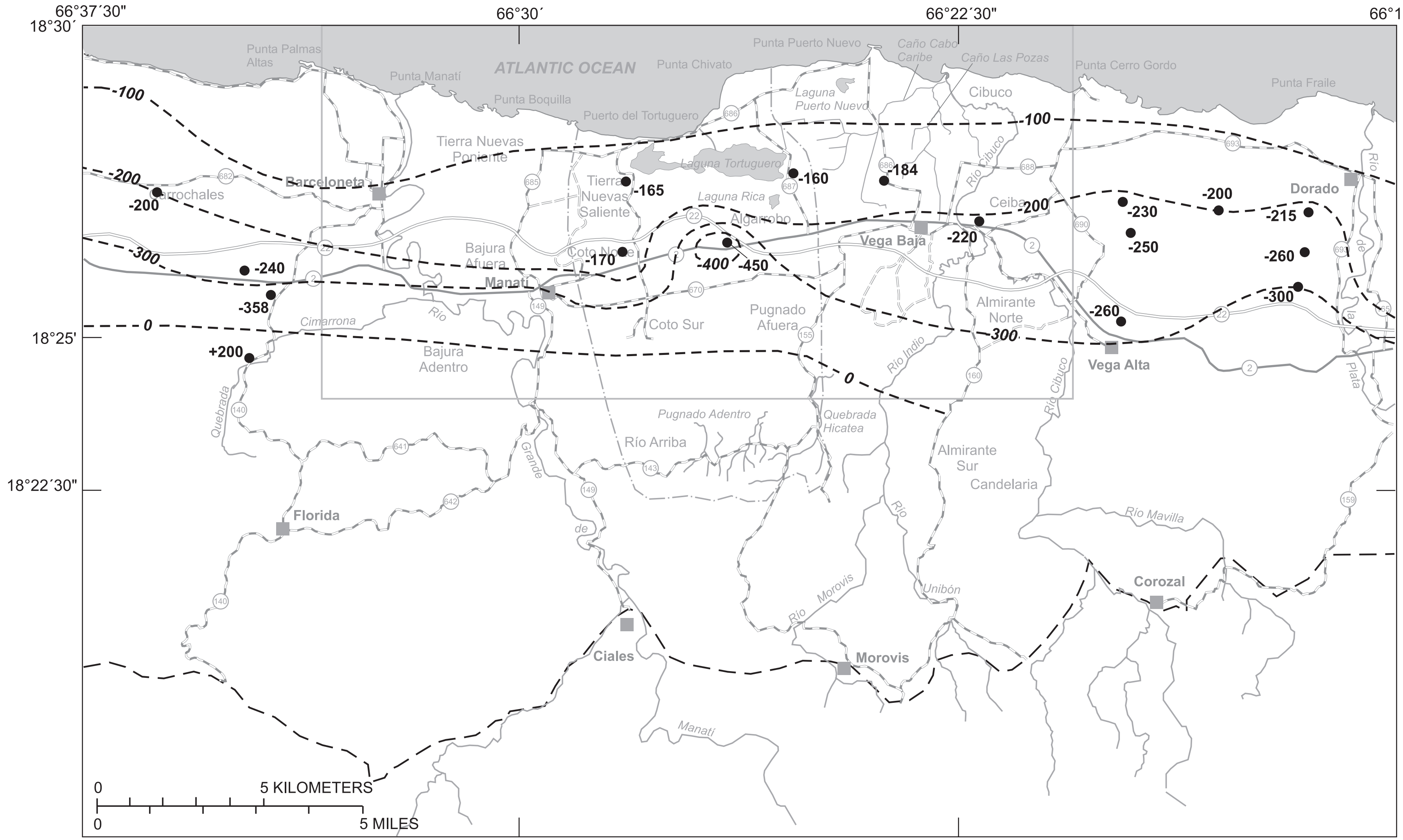
The maximum thickness for limestone units in the study area is 220 ft for the San Sebastián Formation, 850 ft for the Lares Limestone, 1,010 ft for the Cibao Formation, 325 ft for the Aguada Limestone, and 635 ft for the Aymamón Limestone (Monroe, 1980; Rodríguez-Martínez, 1991; Rodríguez-Martínez and others, 1992). The thickness of the alluvial deposits varies greatly along the Río Grande de Manatí and the Río Cibuco. In general, the thickness of the alluvial deposits along the Río Grande de Manatí is 100 ft where deposits overlie the Lares Limestone in the area north of Ciales (S. Torres-González, USGS, written commun., 1999), and to 300 ft downstream where the floodplain widens near Highway PR-2 (Gómez-Gómez, 1984). The thickness of the alluvial deposits along the Río Cibuco varies from approximately 120 ft (Torres-González and Díaz, 1985) in the coastal floodplain near Highway PR-2 to 280 ft downstream along the incised channels of the Río Cibuco near Vega Alta (Gómez-Gómez and Torres-Sierra, 1988). According to drillers' logs of wells in the area, the maximum documented thickness of the surficial "blanket sand" deposits is approximately 110 ft in Barrio Coto Sur of Manatí, but generally is not more than 50 ft (Gómez-Gómez and Torres-Sierra, 1988).

Upper North Coast Limestone Aquifer

The upper aquifer is defined as the saturated, freshwater portions of the Aymamón Limestone, the Aguada Limestone, and the alluvial deposits of the Río Grande de Manatí and the Río Cibuco (fig. 8). The southern boundary of the upper aquifer is south of the Aguada/Aymamón contact near latitude 18°25' (F. Gómez -Gómez, USGS, written commun., 1999), and can be delimited as the southernmost point where the Aguada Limestone is saturated and is considered to be an aquifer. Although the limestone units have a combined thickness of as much as 1,000 ft, the maximum saturated thickness of the freshwater aquifer is approximately 450 ft near Highway PR-2 (fig. 9). The relatively impermeable upper member of the Cibao Formation underlies the unconfined upper aquifer and dips northward at about 3 degrees, causing the freshwater lens to thicken northward towards Highway PR-2, where it is underlain by saltwater. The saltwater wedge thickens and becomes shallower towards the coast, which causes the freshwater lens to thin in that direction (Rodríguez-Martínez and others, 1992) (fig. 8).

Hydraulic Properties

The regional distribution of transmissivities for the upper aquifer can be estimated by two methods: (a) using specific-capacity data available in drillers' well construction logs and applying the Theis and others (1963) method to calculate transmissivity; and (b) using the average hydraulic conductivity estimates for each of the major hydrogeologic units that constitute the upper aquifer in conjunction with areal estimates of the freshwater thickness.



EXPLANATION

- -200 — Altitude of base of the upper aquifer. Datum is mean sea level. Contour, in feet, is variable.
- Boundary of modeled area
- Laguna Tortuguero drainage basin
- Southern extent of North Coast Province
- -170 ● Altitude of base of upper aquifer. Datum is mean sea level.
- Town

Figure 9. Estimated altitude of the base of the upper aquifer in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

To compute transmissivity from specific-capacity data using the Theis and others (1963) method, the following information is needed: aquifer type (confined or unconfined), static water level, pumping water level, well discharge rate, duration of specific-capacity test, effective radius, and the estimated specific yield or storage coefficient. An effective radius of 1 ft was used where no cavernous conditions exist, whereas an effective well radius of 5.0 ft was used for wells penetrating cavernous zones. Conduits in the limestone and the percentage of aquifer thickness penetrated by individual wells can affect computed results of individual pumping tests, so specific capacity data can not be related directly to transmissivity. Calculated transmissivity values for wells that penetrate areas of voids and for wells open to a greater saturated thickness of the same hydrogeologic unit can be erroneously high. Thus, in developing the areal distribution of transmissivity by this method, subjective reasoning must be used in adjusting (or not) the transmissivity value obtained for each well. The transmissivity estimated by the specific capacity or any given methodology, however, applies only to the screened interval of the well, and an adjustment of the calculated transmissivity may not be applicable locally. This is the case where wells indicate that secondary porosity development is highly stratified, as evidenced in the upper aquifer of the Vega Alta area.

The distribution of transmissivity calculated by using the available specific-capacity data indicates there are two areas of high transmissivity near Manatí, and another southwest of Vega Baja. In these areas, the transmissivity values decrease both to the north and south within the limestone units, and in the part of the aquifer contained within the alluvial deposits (fig. 10). Although transmissivity values are relatively high, they are about one half that obtained from the upper aquifer in the adjacent Barceloneta and Vega Alta quadrangles. Southwest of the town of Barceloneta, in the Aymamón Limestone, and north of the town of Vega Alta, in the Aymamón and Aguada Limestones, transmissivity has been estimated to be as high as 150,000 feet squared per day (ft^2/d) (Gómez-Gómez and Torres-Sierra, 1988; Torres-González, 1985; Torres-González and others, 1996). In coastal areas, fine-grained alluvium and marsh deposits may fill the vuggy and locally fissured saturated parts of the Aymamón Limestone, reducing the hydraulic conductivity, as seems to be the case in the coastal plain of the Vega Alta quadrangle area (F. Gómez-Gómez, USGS, written commun., 1999).

The distribution of transmissivity also was calculated using average values of hydraulic conductivity for the two limestone units and the freshwater saturated thickness of the aquifer (fig. 11) determined that the hydraulic conductivity is 160 feet per day (ft/d) for the Aymamón Limestone and 70 ft/d for the Aguada Limestone, and 15 and 10 ft/d, respectively for the alluvial deposits within the Río Grande de Manatí and Río Cibuco valleys. The saturated thickness of the upper aquifer was determined from seven deep and two shallow test holes drilled as part of previous ground-water resources assessments (Rodríguez-Martínez, 1995) (figs. 8 and 9).

The saturated thickness of the alluvium is an estimate based on studies conducted by the USGS, using electric surface resistivity techniques to delineate the depth to the alluvial/limestone contact in the Río Cibuco and the Río Grande de Manatí valleys (Gómez-Gómez, 1984; Torres-González and Díaz, 1984; and S. Torres-González, USGS, written commun., 1998). Transient electromagnetic surveys were conducted along the southern shore of Laguna Tortuguero and areas north to northeast of the lagoon, to estimate the thickness of the freshwater lens in these areas. Values of transmissivity for alluvial deposits in the Río Grande de Manatí and Río Cibuco valleys are based on estimated averages of the hydraulic conductivity of alluvium, which ranges from 25 to 40 ft/d for the lower Río Grande de Arecibo valley (Quiñones-Aponte, 1986), and from 20 to 30 ft/d for the lower Río Grande de Manatí valley (Gómez-Gómez, 1984). Near the coast, the lower transmissivity values are due to the decrease in thickness of the freshwater lens.

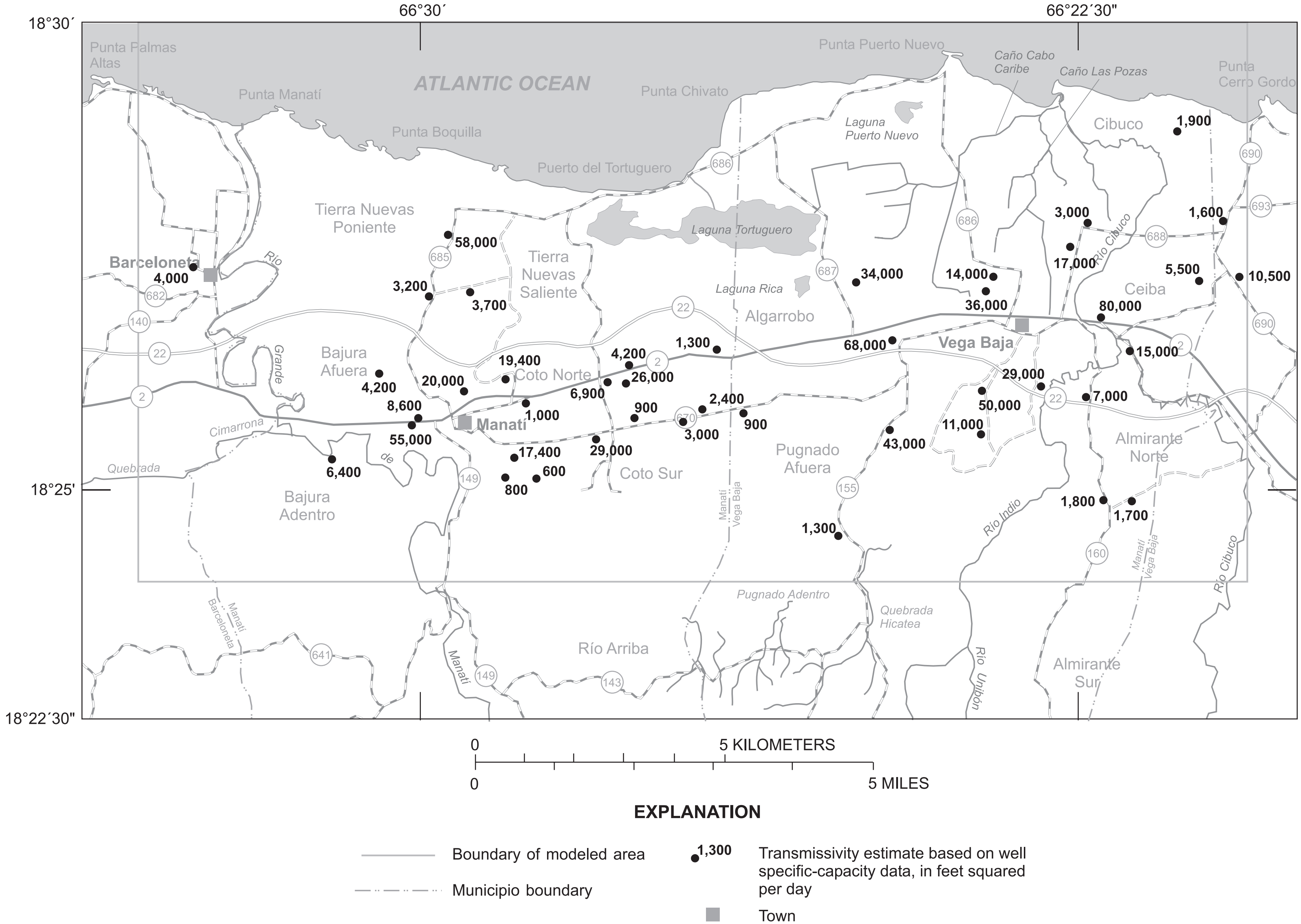


Figure 10. Transmissivity distribution for the upper aquifer as estimated from well specific-capacity data, Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

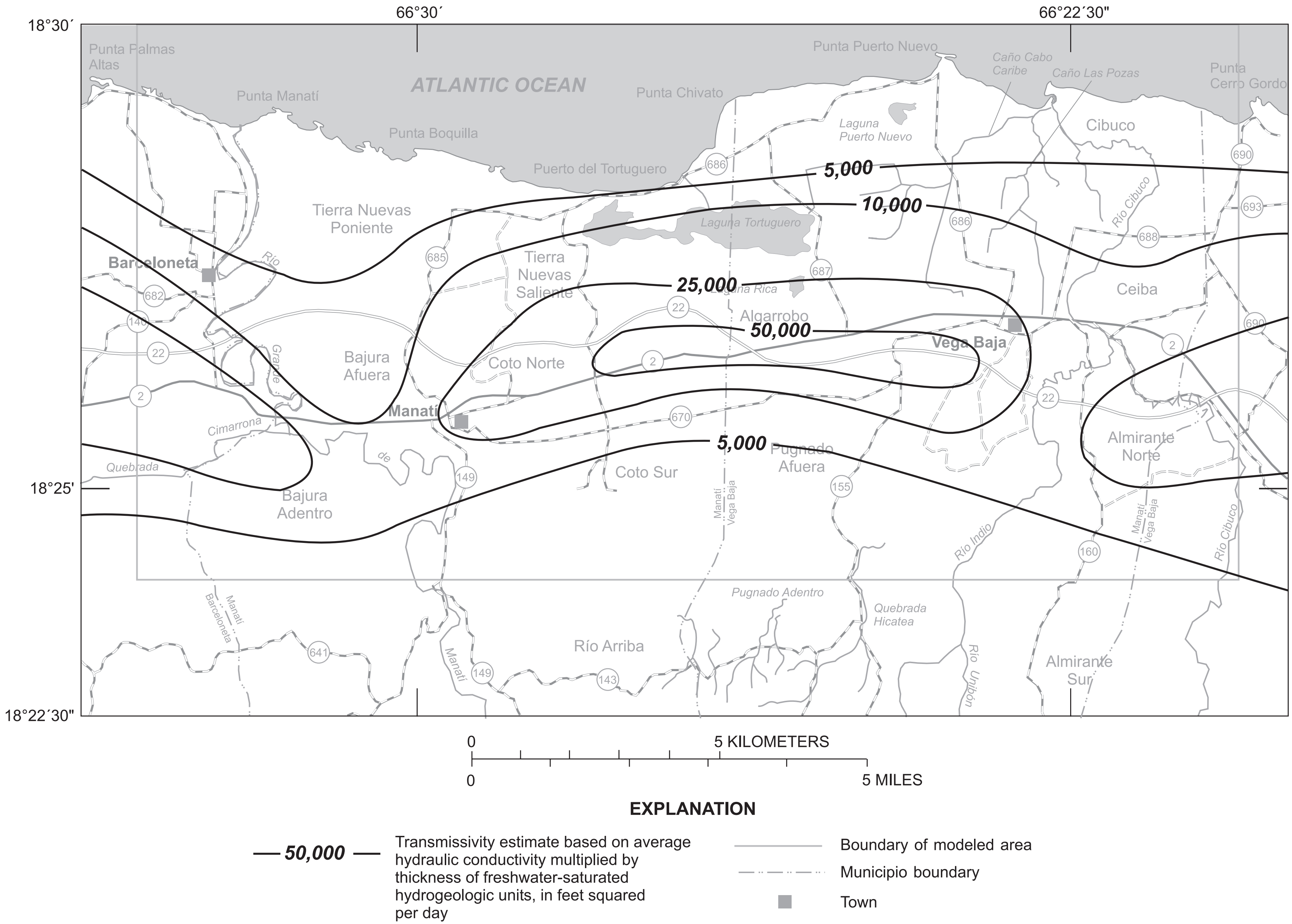


Figure 11. Transmissivity distribution for the upper aquifer as estimated using average hydraulic conductivity values for freshwater-saturated hydrogeologic units in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

Direction of Ground-Water Flow

Ground water in the upper aquifer travels downdip within the Aguada Limestone to the more transmissive Aymamón Limestone. Wells drilled south of the southern aquifer boundary, however, may penetrate a saturated zone within the Aguada Limestone updip of the aquifer. In this area, ground water essentially flows downdip along the bedding plane of the relatively impermeable Cibao Formation until it reaches the upper aquifer (Bennett and Giusti, 1972).

General movement of ground water in the upper aquifer is from the highlands in the karst terrain northward towards Laguna Tortuguero, the coastal plain, and shoreline, as evidenced in the potentiometric surface as mapped in March 1995 (fig. 12). South of Highway PR-670, the water-table gradient reaches 250 ft per mile (ft/mi). This gradient is essentially equivalent to the dip of the top of the confining unit, which regionally averages 3 degrees (equivalent to about 160 ft/mi). The water-table gradient within the upper aquifer from Highway PR-670 at Barrio Coto Sur to the coast, where the upper aquifer exists primarily as a lens of freshwater overlying saltwater, was estimated to range between 3 and 6 ft/mi in 1970 (Bennett and Giusti, 1972) and was found to be 3 ft/mi in 1995 (Conde-Costas and Rodríguez, 1997). The relatively flat potentiometric surface that currently exists is caused in part by ground-water withdrawals, which in the study area have increased from about 5 Mgal/d in 1969 to more than 19 Mgal/d in 1984, and to 17 Mgal/d in 1995 (Bennett and Giusti, 1972; Conde-Costas and Rodríguez, 1997; Molina-Rivera, 1998) (fig. 4). As a result, ground water, which previously would have discharged to Laguna Tortuguero and to the springs south of the lagoon, is presently captured by wells.

Hydraulic Connection with Surface-Water Features

A general summary of the surface-water hydrology for the study area can be obtained from a regional assessment conducted by Giusti and Bennett (1976). This information is useful to determine the interaction of streams and coastal lagoons with the upper aquifer. An overall knowledge of contributing areas to streamflow and flow duration provides valuable insight for accessing river gains and losses to the upper aquifer along various river segments. The hydrologic budgets obtained from that study were the basis for initial recharge estimates used in this study.

According to Giusti and Bennett (1976), between November 1969 and October 1970 (a period with 20 percent above average rainfall), streams draining volcanic rock areas south of the limestone region had a base flow of 1 to 2 ft^3/s per square mile (representing 15 to 25 in. of annual rainfall). In streams draining the limestone terrain of the north coast, Giusti and Bennett (1976) estimated a base flow of only 0.5 to 1 ft^3/s per square mile (representing 7 to 15 in. of annual rainfall). In addition, Giusti and Bennett (1976) also obtained a ratio of base flow to total flow near 0.40 for the limestone region. This ratio of base flow to total flow was used to estimate the surface-water contribution near the southern boundary of the upper aquifer.

Within the study area, the Río Grande de Manatí and Río Cibuco are the only major streams having headwaters in the volcanic terrain and traversing the limestone area. These streams have a combined drainage basin area of 168 mi^2 within the volcanics, and approximately 128 mi^2 within the limestone outcrop areas. With the exception of 6 mi^2 of drainage area near the insular hydrologic divide that is regulated by the Lago Guineo and Lago Matrullas dams, the flow in these streams is unregulated. Gaging stations in the study area at the Río Grande de Manatí near Manatí has been operational from 1970 to the present (50038100), and at the Río Cibuco at Vega Baja near Highway PR-2 (50039500) from 1973 to the present (fig. 3). Prior to the installation of the gaging station for Río Cibuco at Highway PR-2 (50039500), the USGS maintained a gaging station at Central San Vicente (50039600) from 1969 to 1972. In addition to these gaged sites, the USGS has obtained bi-monthly instantaneous discharge measurements at a water-quality station (50038200) at the outlet channel of the Laguna Tortuguero (fig. 3) since March 1974.

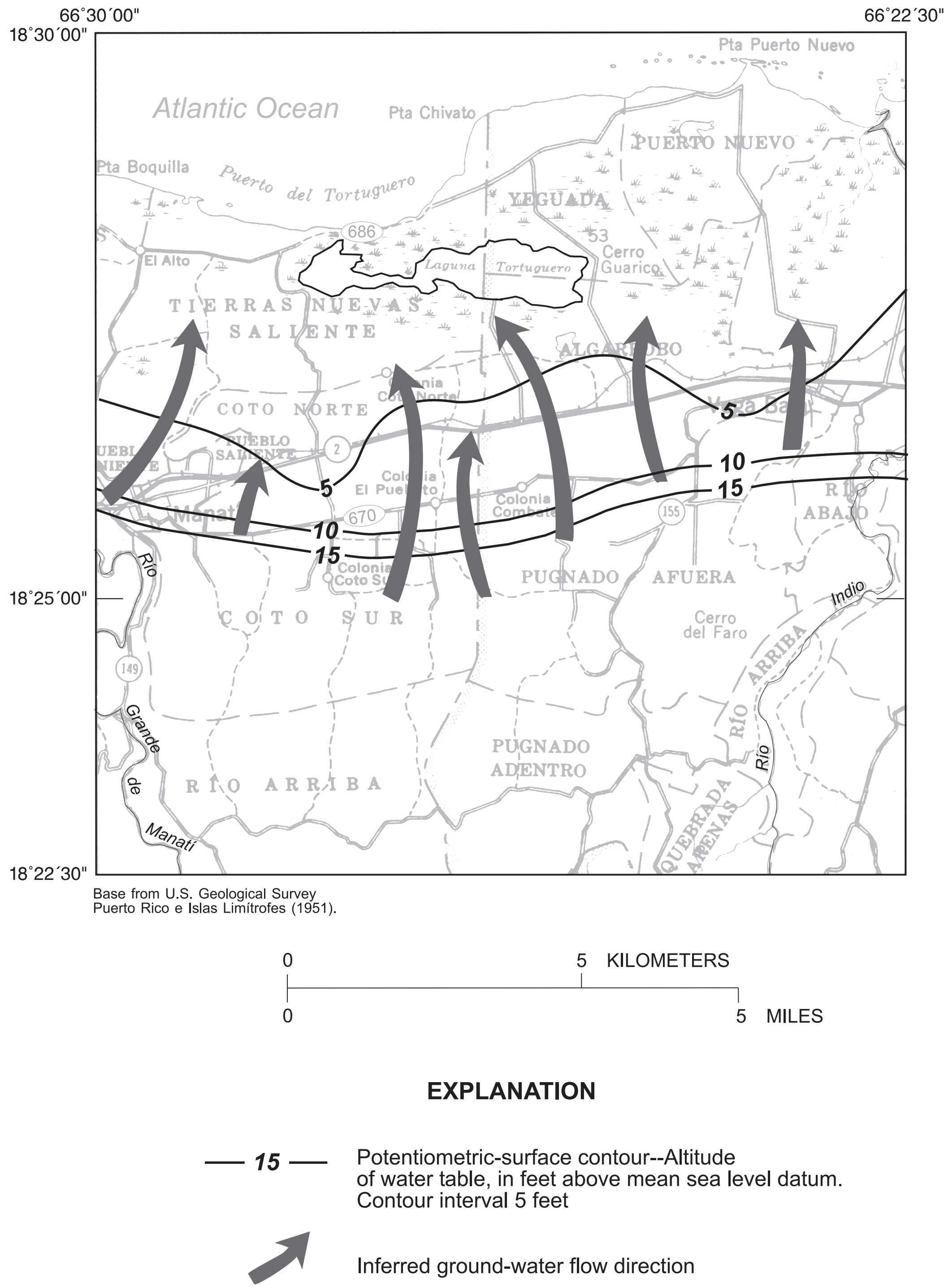


Figure 12. Potentiometric surface of the upper aquifer during March 1995, Manatí quadrangle, North Coast Province, Puerto Rico (modified from Conde-Costas and Rodríguez, 1997).

Discharge from Laguna Tortuguero through the outlet channel to the sea is a combination of ground-water discharge from the upper aquifer and surface-water runoff in the vicinity of the lagoon. The base flow of the Río Grande de Manatí at the gaging station (50038100) averages 105 ft^3/s, with the flow equal to or exceeding 84 ft^3/s about 90 percent of the time (from 1970 to 1997), and a minimum recorded instantaneous discharge of 28 ft^3/s (January 23, 1995). Base flow at the Río Cibuco gaging station averages 31 ft^3/s, with the flow equal to or exceeding 22 ft^3/s about 90 percent of the time (from 1973 to 1997), and a minimum recorded instantaneous discharge of 7.2 ft^3/s (May 2, 1995). The Río Indio and its tributaries contribute approximately 30 percent of the base flow of the gaging station.

Low-flow discharge at the gaged sites have been decreasing, which could be related to streamflow capture upstream primarily for public water-supply purposes, in addition to a general decline of the potentiometric surface in the upper aquifer. Public water-supply withdrawal rates upstream of the gaged stations for 1995 were estimated as follows: 9.9 ft^3/s captured from the Río Grande de Manatí (upstream of the volcanic/limestone contact), 5 ft^3/s captured from the Río Cibuco (upstream from the volcanic/limestone contact), and 3.9 ft^3/s captured from the Río Indio (Molina-Rivera, 1998).

Although a substantial portion of the low flows are captured, these streams also receive discharge from public wastewater treatment plants. The Río Grande de Manatí receives 1.5 ft^3/s (all from locations from the town of Ciales and upstream); the Río Cibuco receives 2.7 ft^3/s, of which, 1.5 ft^3/s is discharged to the stream within the lower valley from the town of Vega Alta and the remainder upstream of the volcanic/limestone contact; and, 0.8 ft^3/s is discharged to tributaries of the Río Indio (Molina-Rivera, 1998).

The most prominent ground-water discharge feature for the upper aquifer is Laguna Tortuguero. The mean annual ground-water discharge into Laguna Tortuguero was estimated as 21 ft^3/s by Bennett and Giusti (1972), which was comparable to the 22 ft^3/s mean annual discharge rate through the ocean outlet channel obtained by Quiñones and Fusté (1978). The average of 30 bi-monthly instantaneous discharge measurements at the outlet canal 50038200, obtained between February 1990 and December 1994, was only 11 ft^3/s (Curtis and others, 1991, 1992; Díaz and others, 1993, 1994, 1995). The apparent reduction in discharge from Laguna Tortuguero to the ocean is probably caused by increases in ground-water withdrawals. The combined effect of dredging the Laguna Tortuguero ocean outlet and ground-water withdrawals has contributed to a general lowering of the water level in the lagoon, which may have been as high as 5 ft above mean sea level prior to 1943, 3.3 ft in the late 1960's (Bennett and Giusti, 1972), 1.5 ft in 1975 (Quiñones-Márquez and Fusté, 1978), and 0.9 ft in 1995 (Conde-Costas and Rodríguez, 1997).

The ground-water/surface-water interaction between the upper aquifer and Río Grande de Manatí, Río Indio, and Río Cibuco was assessed by reviewing available data on stream low-flow discharge rates and duration curves. Several low-flow measurements were made in the lower Río Grande de Manatí as part of this study; low-flow was at near-record levels during the drought period of 1994. The discharge measurements were made for a 1.7 mi reach approximately 5.2 mi upstream and at a point on the river located 3.5 mi upstream of USGS gaging station 50038100 (river reach 1 in fig. 3). North of the reach are two PRASA public-supply wells on Highway PR-2, Manatí 1 and Manatí 2, which have a combined withdrawal rate of 3 ft^3/s. The discharge measurements were made on July 9, 1997, when streamflow had a discharge of 81 ft^3/s. This flow rate is equaled or exceeded more than 90 percent of the time, according to the streamflow record for the period from 1970 to 1997 at gaging station 50038100. The difference in discharge between both sites indicated a loss of 5 ft^3/s to the aquifer, of which 3 ft^3/s could be accounted for by ground-water withdrawals from the two public water-supply wells and an industrial well (Safety Kleen) just north of the two supply wells. Low-flow measurements cannot be used to determine the interaction of the aquifer approximately 3 mi downstream of the gage, since the elevation of the streambed is below sea level (Gómez-Gómez, 1984) and streamflow is affected by tides during low-flow periods.

Ground-water discharge to the Río Indio is indicated by a series of springs along its course and low-flow measurements made on April 3, 1997, and May 6, 1997 (river reach 2 in fig. 3). Net river gains ranging between 1 and 2 ft^3/s were determined by low-flow measurements at low-flow partial-record station 50038895 between Highway PR-646 and Barrio Río Abajo, near Highway PR-22 (Santiago-Rivera, 1998). Low-flow measurements made on February 20, 1959, indicated a net gain for the Río Indio of 3.1 ft^3/s for a reach from latitude 18°23'39" longitude 66°23'42" to latitude 18°26'19" longitude 66°22'13".

Assessment of the surface-water/ground-water interaction between the Río Cibuco and the upper aquifer was obtained as part of a previous study conducted by the USGS to develop a ground-water flow model for the Vega Alta area (Gómez-Gómez and Torres-Sierra, 1988). The Vega Alta area ground-water flow model indicates that the Río Cibuco may be contributing 6 ft^3/s to the upper aquifer. Low-flow measurements made on April 12, 1994, estimated a 5.5 ft^3/s loss to the aquifer.

Recharge

Although some reaches of rivers and streams are important sources of ground-water recharge, most aquifer recharge in this region is from infiltration of rainfall through the limestone outcrops via runoff to sinkholes and enclosed topographic depressions. Within these areas, recharge, which has been estimated by ground-water flow models, is in the range of 10 to 20 inches per year (in/yr) (Heisel and others, 1983; Gómez-Gómez and Torres-Sierra, 1988; and Torres-González and others, 1996).

An estimate of the amount of rainfall and subsequent infiltration into the upper aquifer near the Aguada/Aymamón contact (latitude 18°25') was made as part of this study by taking regular discharge measurements at Quebrada Hicatea (fig. 13). This stream course originates within the outcrop area of the confining unit and ends in a swallow hole near the southern boundary of the study area. The average base flow from periodic flow measurements conducted at Quebrada Hicatea for a 1-year period (June 1997 to May 1998) was 0.2 ft^3/s. By applying the average ratio of base flow to total flow of 0.4 calculated for streams in the North Coast Limestone area (Giusti, 1978), the average discharge for Quebrada Hicatea (June 1997 to May 1998) was estimated to be 0.5 ft^3/s. This estimated discharge for the 1-year period is equivalent to 6 inches per year (in/yr) of rainfall over the drainage area of Quebrada Hicatea. The 6 in/yr probably represents a low recharge estimate, which could average (on a long-term basis) as much as 15 in/yr in this particular area. This range in recharge results from uncertainties associated with defining drainage areas within the limestone terranes, and also because precipitation that occurred during the year in which the discharge measurements were made was only 43.8 in., which was 40 percent below the long-term normal of 70.2 in. for the Morovis station (National Climate Data Center, webmaster@ncdc.noaa.gov, 1998).

Major exceptions to the estimated maximum areal rainfall recharge rate of 20 in/yr can be expected in areas where there is urban development within topographically enclosed depressions. In the Manatí-Vega Baja area, rainfall runoff is conveyed to the upper aquifer by injection wells or storm sewers that discharge to existing sinkholes or caverns. This land-use modification results in a decrease of evapotranspiration, as determined in a study within a 5,000-acre watershed in the upland volcanics of Puerto Rico (Ramos-Ginés, 1997). The results obtained by Ramos-Ginés (1997) indicate that runoff from an urbanized area represented 75 percent of the annual rainfall amount, as compared to an area mostly in secondary forest, which had a runoff of only 36 percent. Thus, if such conditions are extrapolated to the Manatí-Vega Baja area, areal recharge to the upper aquifer from urbanized areas in enclosed topographic depressions could increase from 20 in/yr to as much as 42 in/yr, due to additional runoff directed to the aquifer.

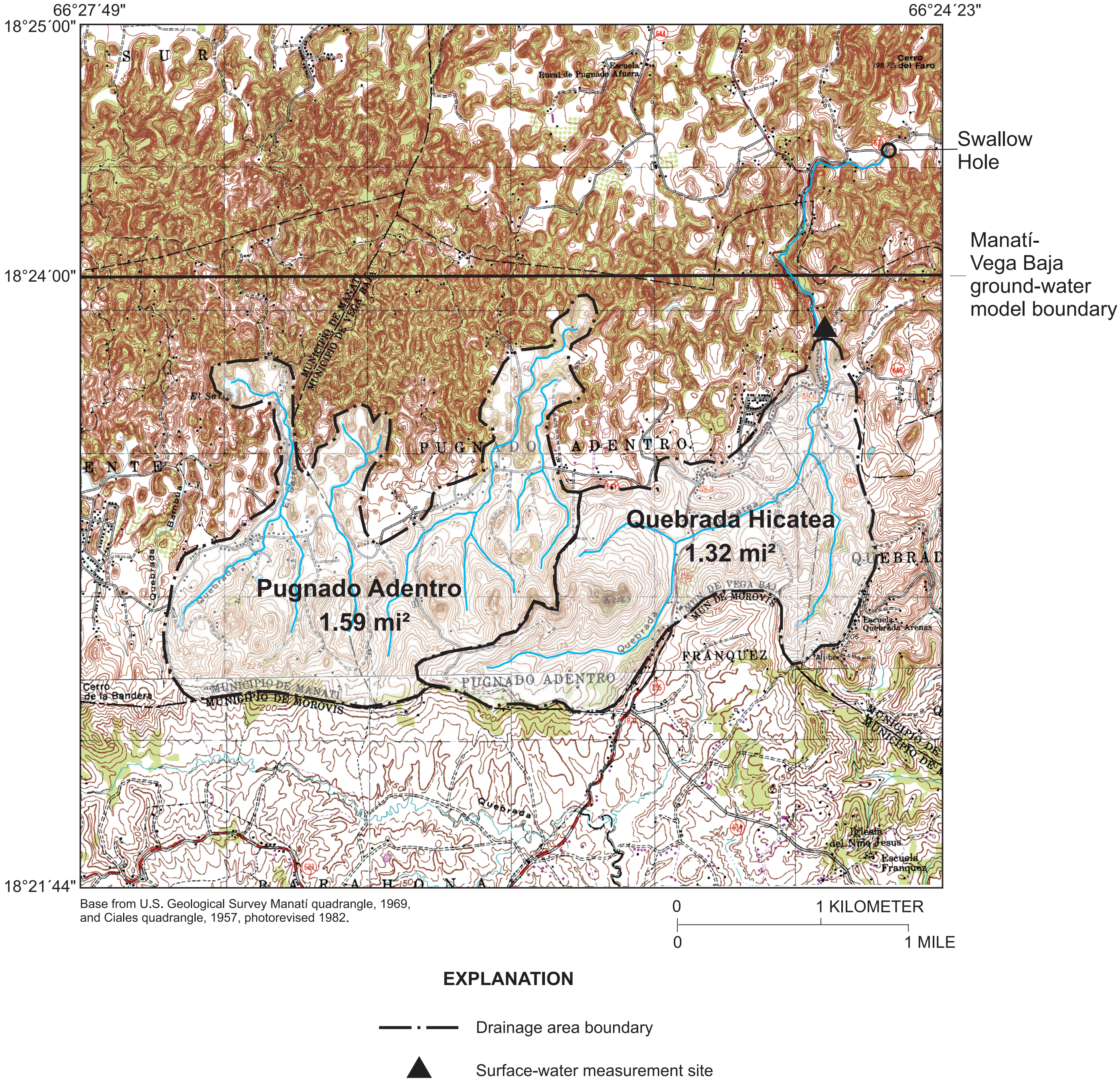


Figure 13. Location of surficial drainage areas along the southern boundary of the upper aquifer, North Coast Province, Puerto Rico (see figure 3 for location in the Manatí-Vega Baja study area).

Discharge to Springs

In addition to ground-water discharge to Laguna Tortuguero, numerous springs and seeps are reported in the coastal wetland areas. Major springs are located near Vega Baja (Ojo de Agua), south of Laguna Tortuguero, near the junction of Highway PR-2 and Río Grande de Manatí (Ojo de Guillo), and Tierras Nuevas Poniente (Mamey) (Springs 3, 4, 15, 27, and 106; fig. 5 and table 1). These third-order diffuse-type springs have base flows ranging from 1 to 6 ft^3/s (Rodríguez-Martínez, 1997). An instantaneous discharge measurement of 2.3 ft^3/s was obtained for the springs south of the lagoon near the inflow channel to Laguna Tortuguero during a relatively dry period in August 1997 (fig. 3). Springs in the municipios of Manatí and Vega Baja contributed substantially to for public water supply, providing 0.4 Mgal/d in 1959 (Arnow and Crooks, 1960).

Confining Unit within the North Coast Limestone Aquifer System

According to Rodríguez-Martínez (1995), the confining unit to the lower aquifer between Manatí and Vega Baja consists not only of the upper member of the Cibao Formation, but also includes the underlying Quebrada Arenas and the Río Indio Limestone Members of the Cibao Formation, and the informally named mudstone unit (figs. 5, 7, and 8). The total thickness of these units at test wells NC-4 and NC-14 was 991 and 837 ft, respectively. The upper member of the Cibao Formation maintains a relativel constant thickness of about 165 ft from the Río Grande de Manatí to the east of study area (Monroe, 1980).

Giusti (1978) estimated an average hydraulic conductivity of 1.4 ft/d for the Cibao Formation in the Manatí-Tortuguero area. This estimate, however, is thought to be based on pumping tests for wells screened or open to the upper member of the Cibao Formation and units above. No wells open to only the upper member of the Cibao Formation are known to exist. Hydraulic conductivity values from slug tests at the Vega Alta Superfund Site (located east of Vega Baja), conducted in the upper member of the Cibao Formation, range from 0.005 to 1 ft/d, within an area where the confining unit is considered leaky (Geraghty & Miller, 1992).

Lower North Coast Limestone Aquifer

The lower aquifer is contained within the Montebello Limestone Member of the Cibao Formation and the Lares Limestone (figs. 5 and 8). The lower aquifer was found to contain ground water under artesian conditions in 1968, when two industrial waste injection wells were drilled in the Cruce Dávila area of Barceloneta (Giusti, 1978). The lower aquifer is hydraulically separated from the upper aquifer in the study area by the upper member of the Cibao Formation. The lower aquifer has been developed as a source of water for industrial use in the municipios of Barceloneta and Manatí.

SIMULATION OF GROUND-WATER FLOW IN THE UPPER AQUIFER

The USGS MODFLOW computer code was used previously to simulate two-dimensional flow in the upper aquifer in the North Coast Limestone aquifer system at Barceloneta (Torres-González, 1985), Vega Alta (Gómez-Gómez and Torres-Sierra, 1988), Aguadilla to Río Camuy (Tucci and Martínez, 1995), and at the Río Camuy to Río Grande de Manatí area (Torres-González and others, 1996) (fig. 14). The potentiometric-surface map of March 1995 was used as a starting point for the conceptualization and construction of the model of the upper aquifer within the study area (fig. 12). The area modeled was extended further west and east to simulate the interaction between major streams and the upper aquifer. A steady-state simulation was calibrated to the observed hydrologic conditions for March 1995 along with an additional steady-state simulation for 1940 hydrologic conditions. A transient simulation was initiated for 1940 conditions with the historical pumping simulated in 10 stress periods up to 1995. The aquifer heads generated for the transient simulation were compared to the calibrated steady-state model for March 1995.

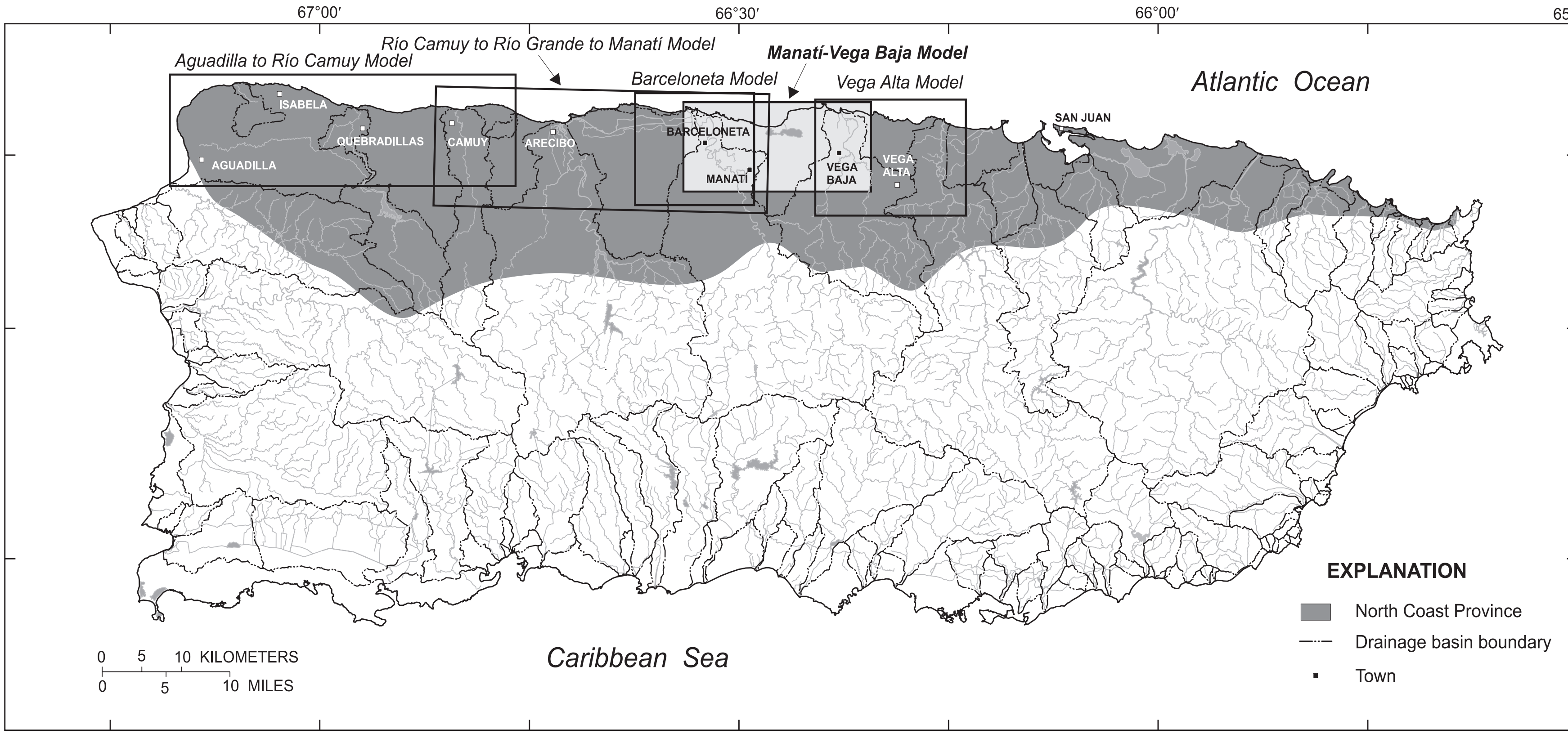


Figure 14. Areas in which digital ground-water flow models have been developed in the North Coast Limestone aquifer system, Puerto Rico.

Model Assumptions

One of the principal requirements in using MODFLOW is that Darcy's law is applicable to calculate the flux between each finite difference cell. This equation is valid for ground-water flow problems if the velocity is slow and laminar. The equation is not valid for turbulent flow through caverns and dissolution channels or conduits. In the case of the upper aquifer, the secondary porosity of the Aymamón Limestone is high and it is probable that preferential flow paths and conduits exist. The high variability in transmissivity recorded in selected wells (fig. 10) probably results from individual wells tapping different fracture zones and dissolution channels.

In order to model a system where caverns and dissolution channels exist, "a simplification is to assume laminar flow everywhere and an effective transmissivity that is uniform throughout each cell of the model such that conservation of mass is preserved along with known hydraulic gradients" (Kuniansky and Holligan, 1994). This simplification is justified, since the principal purpose of the model is to improve our knowledge of the water balance for the upper aquifer by simulating various hydrologic conditions and scenarios brought about by hydrologic modifications to the flow system, such as dewatering wetlands and aquifer withdrawals.

The USGS MODFLOW-96 computer model code (Harbaugh and McDonald, 1997) was used to simulate ground-water flow in the unconfined upper aquifer. The computer code uses finite-difference techniques to solve the water-balance equations for ground-water flow within the aquifer, taking into consideration sources (primarily recharge from rainfall infiltration and seepage from surface-water bodies), sinks (primarily discharge to surface-water bodies, evapotranspiration, or wells), and change in storage (water-level changes). MODFLOW can be used for three-dimensional analysis, and for steady or transient flow in anisotropic and heterogeneous ground-water flow systems. For the purpose of this study, the upper aquifer was simulated as a two-dimensional system. Model assumptions included that ground-water flow through the upper aquifer is predominantly horizontal, fluctuations in aquifer head are not sufficient to alter the saturated thickness, and the lower aquifer is hydraulically independent from the upper aquifer due to the confining unit. The unconfined upper aquifer was simulated as a confined system, because the saturated thickness is relatively constant, thus the transmissivity is assumed constant.

Prior to defining the boundary conditions for the model, the following general assumptions were made:

1. Aquifer transmissivity values assigned are independent of water-table changes in transient simulations. This assumption can be justified because ground water throughout the major part of the aquifer occurs through preferential horizontal flow planes (zones in which the hydraulic conductivity is substantially higher), possibly as the result of preferential dissolution of the hydrogeologic units along the water-table plane of previous sea level stands. These zones of high hydraulic conductivity were documented within the upper aquifer in the Vega Alta area (Gómez-Gómez and Torres-Sierra, 1988). At Vega Alta, a high hydraulic conductivity zone was documented between 70 to 120 ft below mean sea level. This zone represents 33 percent of the estimated transmissivity in that area.
2. The saltwater/freshwater boundary is a sharp interface and static beneath the freshwater part of the aquifer. Although known to have changed, the effect is most important to ground-water quality variations across the aquifer thickness, and less important in water-balance computations.
3. The aquifer is at equilibrium under the hydrologic conditions used as initial conditions of March 1995 (fig. 15). This assumption is least certain within the area directly south of Laguna Tortuguero, as evidenced by the cone of depression along Highway PR-2 (Renken and Gómez-Gómez, 1994) and the inland displacement of the potentiometric surface within the western part of the Manatí quadrangle, where ground-water withdrawals have increased substantially.
4. Areal rainfall/runoff recharge rates are maintained constant for the simulation period. Rainfall intensities sufficient to induce recharge and runoff occur primarily in a stochastic manner, and is most important during the wetter months of the year.

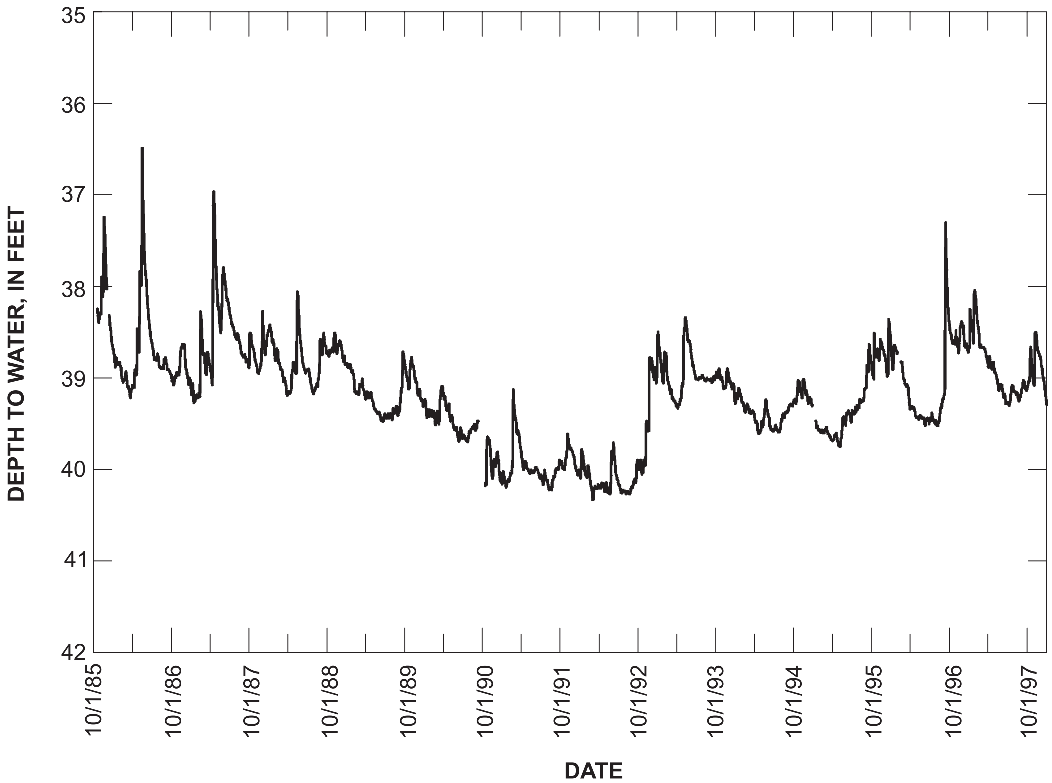


Figure 15. Hydrograph of ground-water levels at well 105 (Cantito La Luisa), Manatí area, Puerto Rico (refer to figure 6 for well location).

For long-term simulation, as is the case in this analysis, partitioning of rainfall recharge rates as a function of measured rainfall is not merited.

5. Stream stages remain constant. This is not a sensitive parameter, since the annual variation in stage of the two major streams at the gaging-station sites between the 90th percentile of flow (base flow conditions) and the 10th percentile of flow (flood stage conditions) is 3 ft for the Río Grande de Manatí and 0.8 ft for the Río Cibuco, and the following assumption (6) holds.
6. Ground-water withdrawal rates, as reconstructed from available records, are constant for the given length of the stress periods used. This assumption is generally acceptable since most ground-water withdrawals in the area are for public water-supply purposes, and such wells operate at relatively constant discharge rates.

All properties assigned to each cell represent average values in the area of that cell. To run the model, parameters must be assigned for initial conditions that should represent, as nearly as possible, steady-state conditions within the aquifer (inflow equals outflow with no change in storage). Input parameters must be provided for the starting heads, transmissivity, rates of areal aquifer recharge from rainfall/runoff infiltration, streambed/seabed conductance, and ground-water withdrawals. Under ideal conditions, the best representation of steady-state conditions in the model area was that which existed prior to dredging of an ocean outlet connecting Laguna Tortuguero with the Atlantic Ocean in 1943, when aquifer development was negligible. No data exist, however, on the distribution of the potentiometric surface or hydrologic fluxes prior to this date. The alternate option available for assignment of aquifer properties is to assume that aquifer conditions during March 1995 (only reference date for which data are available on potentiometric-surface distribution, ground-water withdrawal rates, and discharge at the Laguna Tortuguero outlet) are representative of steady-state conditions under the estimated aquifer water balance.

Grid Design and Boundary Conditions

A model grid was designed with the columns generally oriented parallel to the direction of ground-water flow or head gradient, in the north-south vector with grid blocks (1,000 X 1,000 ft) divided into 36 rows and 73 columns (fig. 16). Although the altitude of the bottom of the aquifer is not essential in the two-dimensional code of MODFLOW, in this case, the bottom of the aquifer corresponds to the top of the upper member of the Cibao Formation from the southern model boundary to the area, where the upper aquifer attains a maximum thickness of 450 ft (fig. 9). North of this line, the lower boundary of the upper aquifer is delimited by the saltwater/freshwater interface. The southern boundary of the ground-water flow model was established at latitude 18°24', to include aquifer recharge originating from rainfall infiltration at outcrops of the Aguada Limestone. The southern boundary is represented as a no-flow boundary, except where runoff over the Cibao Formation occurs, a hydrologic condition represented in the model by injection wells located in rows 33 to 36**.** The western and eastern edges of the model area are no-flow boundaries beyond the Río Grande de Manatí to the west and the Río Cibuco to the east. These boundaries were extended beyond the rivers to simulate the surface-water/ground-water interaction in the area of the rivers, and to minimize computational errors resulting from the effects of model boundaries.

Internal Boundaries

The interaction between streams and the aquifer was modeled by using the River Package (McDonald and Harbaugh, 1988) in the model cells for which exchange of water exists (part of stream course for which data are available showing gaining or losing reaches) or is suspected (such as the estuary parts of streams and drainage channels in wetland areas that are not gaged). Riverbed conductance is defined in MODFLOW as:

$$C = (Kz/m) \times (L) \times (W),$$

where

- Kz is the streambed vertical hydraulic conductivity,
- m is the thickness of the riverbed,
- L is the length of the stream segment within the model cell area, and
- W is the average width of the stream segment.

Since Kz/m is generally unknown for most conditions, C is determined indirectly by varying the value as part of the model calibration process. Modeled streamflow gains (discharge from aquifer) or losses (recharge from stream) are compared with observed data for segments where data are available. Model calibration is achieved by matching modeled gains and losses in the stream with observed data, and by matching modeled heads at and near the stream with observed water levels in the aquifer. Flow between the stream and the aquifer is governed by the conductance of the riverbed and the relation between stage in the stream and head in the aquifer, as described in the equation:

$$Q = C \times [Hs - Ha],$$

where

- Q is the flow between the stream and the aquifer, taken as positive if directed into the aquifer,
- C is the hydraulic conductance of the stream-aquifer interconnection,
- Hs is the assigned head value for the water surface in the stream segment, and
- Ha is the input aquifer head value for the model cell.

For stream segments where no streamflow gain or loss data are available, the conductance values are assigned indirectly by trial and error until the modeled areal head distribution is in general agreement with the input calibration potentiometric-surface distribution.

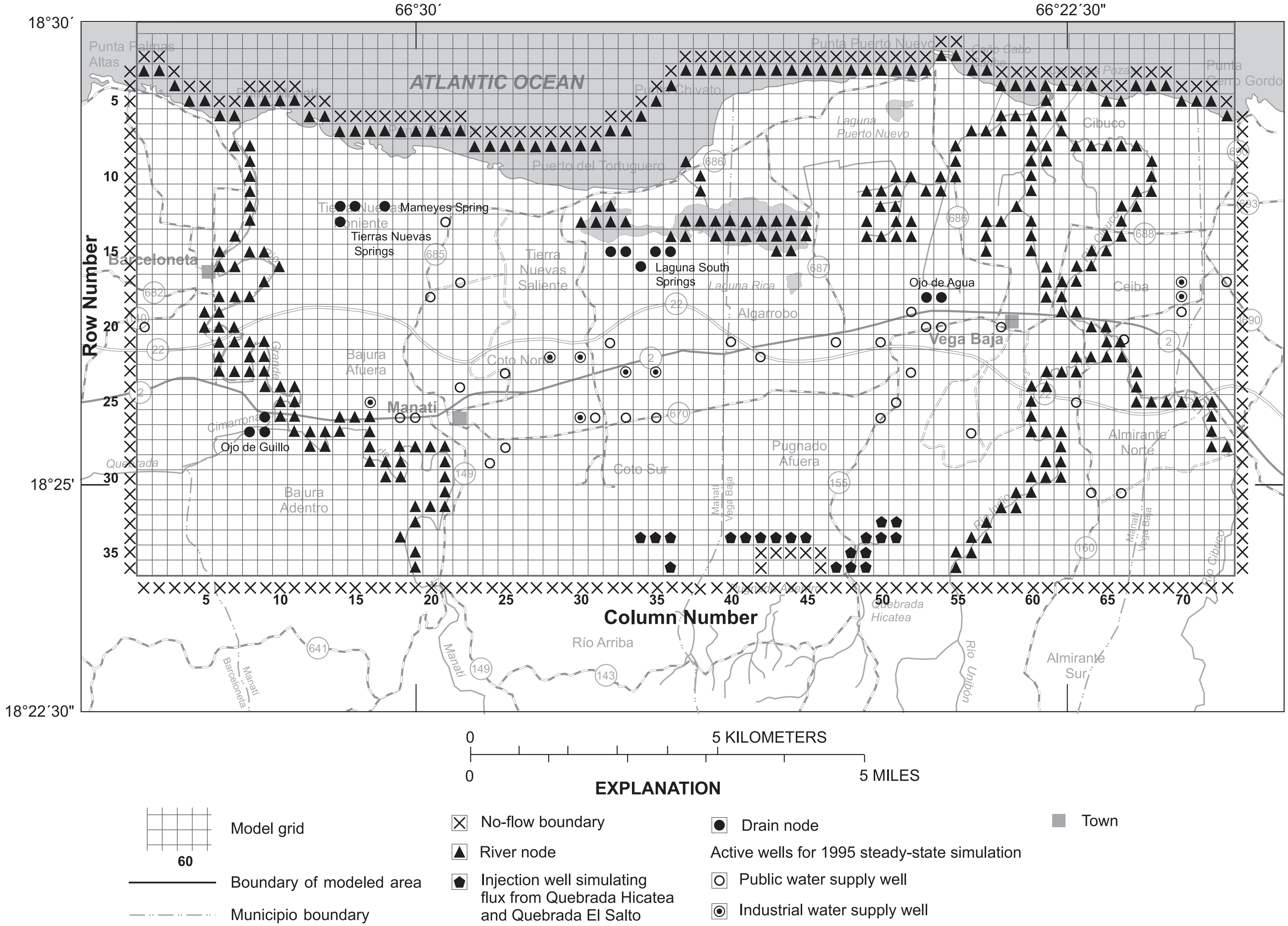


Figure 16. Model grid and boundary conditions of the upper aquifer in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

The River Package was also used to simulate the interaction between the upper aquifer and Laguna Tortuguero. The seabed along the coast of the Atlantic Ocean was represented as a streambed with a head of 0.0 ft. The head gradient of the aquifer along the coast was sufficient to avoid the adverse impact of artificial input into the model from river cells. The high gradient between the upper aquifer near Laguna Tortuguero and the Atlantic Ocean during 1940 conditions required moving the boundary north near Puerto del Tortuguero. This is also in general agreement with reported offshore springs in the area.

The model input requirements in MODFLOW for simulating streams are the head in the stream, Hs, riverbed conductance, and riverbed bottom elevation. The head is computed by taking the streambed altitude values estimated from 1:20,000 scale topographic maps and field observations, and adding a value of stream depth ranging from 0.2 to 1.1 ft. Initial riverbed conductance values were taken from other models for the Río Grande de Manatí (Torres-González and others, 1996) and the Río Cibuco (Gómez-Gómez and Torres-Sierra, 1988). The riverbed conductance values for the Río Cibuco were also used for the Río Indio and adjusted according to the aquifer gains and losses recorded during seepage runs made between the bridge at Highway PR-674 (Río Arriba) north to the overpass at Highway PR-22. The riverbed conductance values for Laguna Tortuguero were assigned by using an estimated vertical hydraulic conductivity multiplied by the cell dimensions. The stage level for Laguna Tortuguero of 0.9 ft was surveyed for the work conducted in March 1995 (Conde-Costas and Rodríguez, 1997). The number of river cells assigned for Laguna Tortuguero were based on the computed area. The ground-water fluxes to the lagoon were estimated from previous studies (Bennett and Giusti, 1972) and monthly discharge measurements taken at USGS gaging station 50038200.

The major springs in the study area were simulated using the Drain Package within MODFLOW (McDonald and Harbaugh, 1988). The model input requirements for this package include the elevation of the spring or seep and a conductance value. If the head in the aquifer is lowered below the specified drain elevation, then there is no exchange between the aquifer and the drain (spring) is dry. The location of the third-order diffuse-flow springs where the drain package was used is shown in figure 16. The spring elevation values were estimated from 1:20,000 scale topographic maps and Ojo de Agua near Vega Baja (fig. 16) was referenced to mean sea-level datum using third-order leveling (Conde-Costas and Rodríguez, 1997).

Simulated Recharge and Discharge

Using the mass-balance approach, a maximum aquifer recharge rate for the karst terrain in northern Puerto Rico was established at 20 to 25 in/yr (Bennett and Giusti, 1976). The remaining 40 to 50 in/yr from the average yearly rainfall of 60 to 75 in/yr is conveyed by evapotranspiration. Ground-water flow models constructed for the North Coast Limestone aquifer system have used varying maximum rates of ground-water recharge to the upper aquifer: 17.5 in/yr (Geraghty & Miller, 1992), 19.5 in/yr (Gómez-Gómez and Torres-Sierra, 1988), 19.7 in/yr (Heisel and others, 1983), 20 in/yr (Torres-González and others, 1996), 22 in/yr (Tucci and Martínez, 1995), and 25 in/yr (Torres-González, 1985). Initially for the steady-state model, the recharge rate for areas with closed depressions or areas with poorly defined surface-water drainage was assigned a maximum value of 18 in/yr (fig. 17).

The rainfall/runoff recharge at outcrop areas south of latitude 18°25’ are based on regular discharge measurements made along the Quebrada Hicatea for a 1-year period. As an initial input, the recharge south of latitude 18°25’ was estimated to be 8 in/yr, which is slightly greater than the maximum estimate of 6 in/yr calculated for the Quebrada Hicatea for the period from June 1997 to May 1998, which was measured under drier-than-normal conditions. The 8 in/yr of rainfall/runoff recharge along the area south of 18°24’ was simulated using injection wells near the southern model boundary (fig. 16). The estimated discharge along Quebrada Hicatea of 0.5 ft^3/s was used to estimate inflow for drainage areas with similar characteristics to the west (figs. 13 and 16). The total flux to the aquifer from surficial drainage over the Cibao Formation in its outcrop area to the upper aquifer along the southern boundary of the model was estimated to be equivalent to an injection rate of 1.6 ft^3/s.

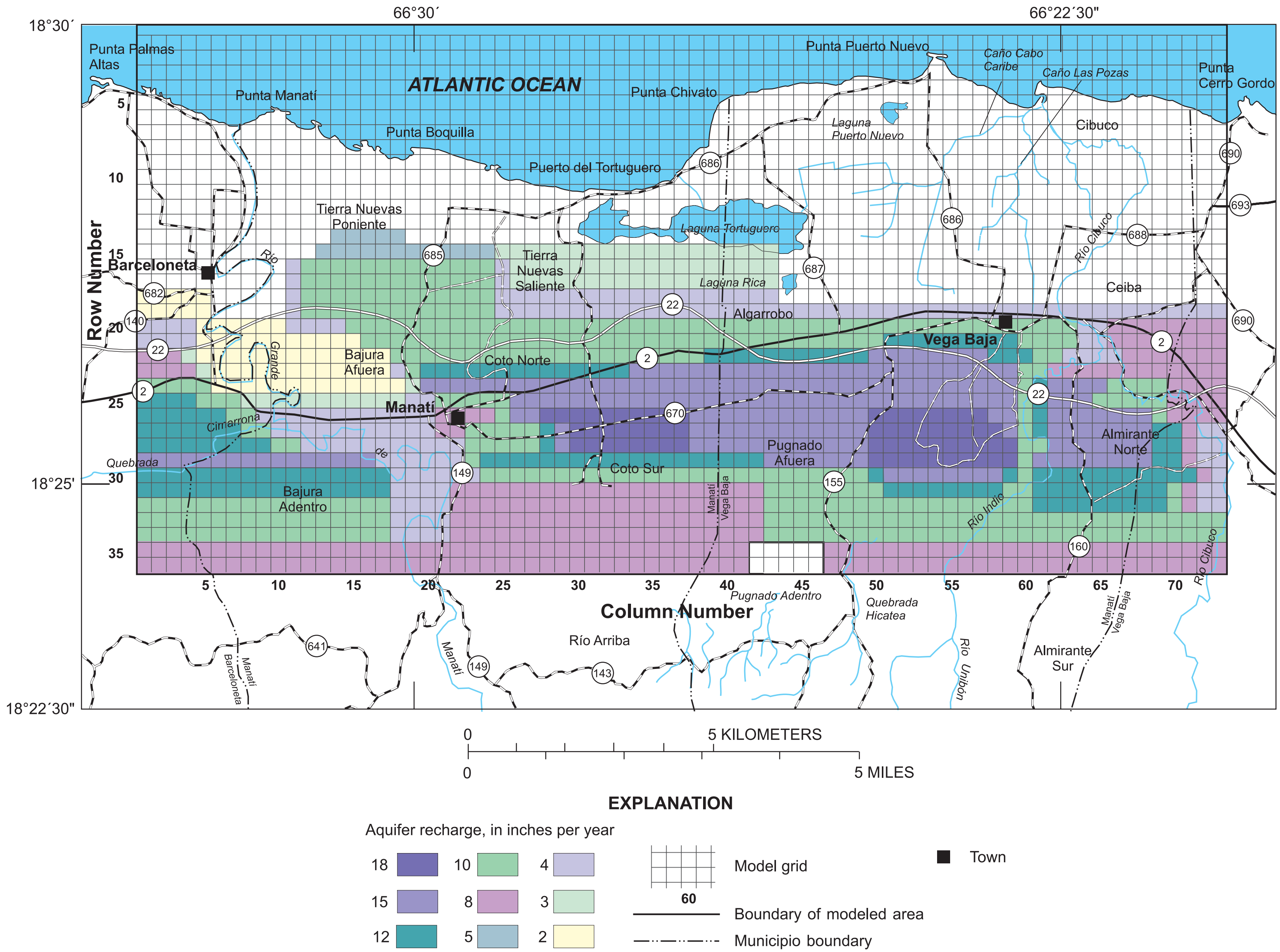


Figure 17. Calibrated recharge distribution used for the digital ground-water flow model simulations of the upper aquifer system in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

A minimum recharge of 2 in/yr was applied to the modeled alluvial valley of the Río Grande de Manatí north of Highway PR-2, and 4 in/yr in other areas having substantial alluvial deposits. These relatively low recharge valves were used, since most rainfall infiltration in the alluvial valleys is probably discharge rapidly to streams. This condition represents a local flow system, and the recharge does not reach the upper aquifer.

Ground-water withdrawal rates assigned in model cells for initial conditions correspond to the pumpage rates documented for hydrologic conditions in March 1995 and the potentiometric-surface map prepared by Conde-Costas and Rodríguez (1997) (fig. 12). The ground-water withdrawal rates used for the transient model simulation correspond to the historical pumpage rates reconstructed from PRASA public water-supply and the PRDNER records, and the USGS water-use database, which includes production data for industrial, public water-supply, and irrigation uses. The reconstructed ground-water withdrawal estimates and stress periods used in the transient simulation are given in figure 18 and table 2. Springs within the modeled area were simulated using the drain package in cells where springs are located. The total discharge for the springs were obtained from previous studies: the flow rate for the springs south of Laguna Tortuguero was estimated to range between 6 and 8 ft^3/s, based on a ground-water model developed for a proposed harbor construction project (Bennett and Giusti, 1972); estimates of flow rates used in the model calibration process for Ojo de Guillo, Mameyes, Isidora springs in the lower Río Grande de Manatí, and Ojo de Agua spring at Vega Baja are from Gómez-Gómez (1984), Guzmán-Ríos (1988), and Rodríguez-Martínez (1997), in addition to field verification measurements made during the study. The spring discharge rates were used in adjusting the drain conductance values, as part of the model calibration process.

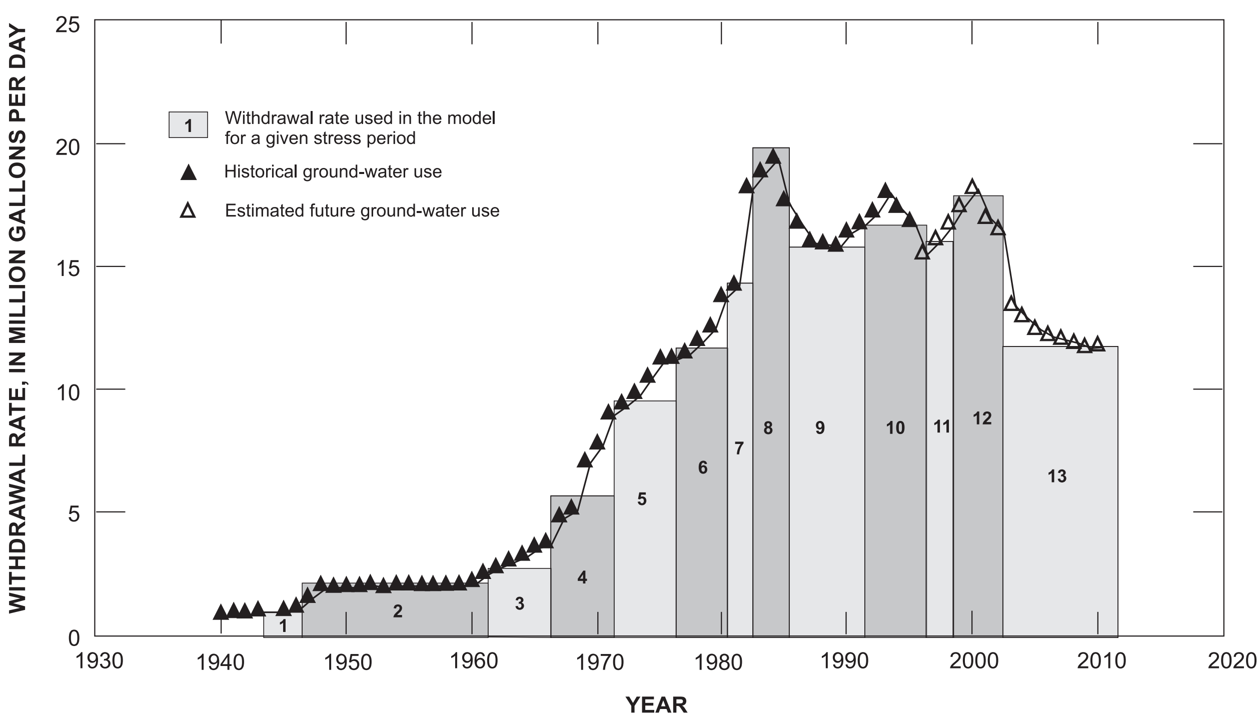


Figure 18. Ground-water withdrawal rates used for each stress period for the transient simulations, Manatí-Vega Baja model area, North Coast Province, Puerto Rico (see table 2 for individual well pump rates used).

Table 2. Ground-water withdrawal rates used for the Manatí–Vega Baja transient simulation for each stress period

[PS, public supply well; Ind, industrial supply well; Irr, irrigation well; Mn, mining well; NA, information unavailable; Mgal/d, million gallons per day]

Well name	Year drilled	Use of water	Stress period and associated withdrawal rate in Mgal/d									
			1 1943-45	2 1946-60	3 1961-65	4 1966-70	5 1971-75	6 1976-79	7 1980-81	8 1982-84	9 1985-90	10 1991-95
Ceiba 1	1931	Irr	0.078	0.079	0	0	0	0	0	1.15	0	0
Ceiba 2 Carmelita	1931	Irr	0.078	0.079	0	0‘pO	0	0	0	0	0	0
Santa Rosa	NA	PS	0.078	0.078	0.634	0.634	0.634	0.634	0.634	0.634	0	0
Campo Alegre	1930	PS	0.1	0.1	0	0	0	0	0	0	0	0
Rice Program 3	1934	Irr	0.078	0.078	0	0	0	0	0	0.72	0	0
Central San Vicente	1932	Ind	0.15	0.15	0.15	0	0	0	0	0	0	0
Tortuguero 1	1940	PS	0.1	0.1	0.1	0	0	0	0	0.09	0	0
Tortuguero 2	1940	PS	0.1	0.1	0.1	0	0	0	0	0	0	0
Tortuguero 3	1940	PS	0.1	0.1	0.1	0	0	0	0	0	0	0
Fortuna	1930	PS	0.078	0.3	0.3	0.4	0.52	0.52	0.52	0.52	0.18	0.33
Manatí 1	1947	PS		0.3	0.3	1.0	1.1	1.1	1.1	1.3	1.17	1.03
Manatí 2	1947	PS		0.3	0.3	1.0	1.0	1.0	1.0	1.2	1.0	0.95
Vega Baja 1	1948	PS		0.1	0.15	0.36	0.36	0.36	0.36	0.36	0.32	0.17
Coto Norte 1	1947	PS		0.04	0.1	0.28	0.28	0.28	0.28	0.28	0	0
Pugnado Afuera 1	1950	PS		0.05	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.45
China Caribe	1952	PS		0.05	0.05	0	0	0	0	0	0	0
Kirk Wing	1954	Ind		0.06	0.06	0	0	0	0	0	0	0
Cubano Jacinto	1956	Irr		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sabana Hoyos 1	1959	PS			0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
Agregado	1960	Mn			0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28
Coto Norte 2	1966	PS				0.19	0.19	0.19	0.19	0.19	0.04	0
Coto Sur 1	1967	PS				0.64	0.7	0.8	0.8	0.8	0.66	0.92
Warner Lambert 1	1967	Ind				0.045	0.045	0.045	0.045	0.045	0.045	0.08
Oficina PRASA	1968	PS				0.3	0.6	0.6	0.6	0.6	0.7	1.03
Vega Baja 2	1969	PS					1.0	1.0	1.0	1.0	0.44	0.54
Sabana Hoyos 2	1969	PS					0.1	0.1	0.1	0.1	0.07	0.3
Vega Baja 3	1970	PS					1.0	1.2	1.2	1.3	1.3	1.28
Schering Plough 1 & 2	1970	Ind					0.3	0.6	0.7	0.72	0.6	0.66
Sabana Hoyos 3	1971	PS					0.1	0.2	0.2	0.2	0.2	0.2
Almirante 2	1971	PS					0.1	0.12	0.12	0.12	0.12	0.12

Table 2. Ground-water withdrawal rates used for the Manatí–Vega Baja transient simulation for each stress period—Continued

Well name	Year drilled	Use of water	Stress period and associated withdrawal rate in Mgal/d									
			1 1943-45	2 1946-60	3 1961-65	4 1966-70	5 1971-75	6 1976-79	7 1980-81	8 1982-84	9 1985-90	10 1991-95
Coto Sur 2	1971	PS					0.2	0.24	0.24	0.24	0.17	0
Warner Lambert 2	1971	Ind					0.045	0.045	0.045	0.045	0.045	0.08
Davis & Geck N & S	1974	Ind					0.1	0.2	0.2	0.24	0.25	0.25
Eaton Labs	1974	Ind					0.07	0.07	0.07	0.07	0.07	0.07
Inland Chemical	1974	Ind					0.2	0.6	0.6	0.6	0.58	0.43
Coto Sur 3	1974	PS					0.2	0.53	0.6	0.75	0.51	0
Roche	1974	Ind						0.14	0.14	0.14	0.14	0.16
Boquillas	1978	PS						0.13	0.52	0.53	0.45	0.43
Rabano	1979	PS						0	0.2	0.32	0.45	0.42
Coto Sur 4	1979	PS						0.1	0.27	0.26	0.23	0.18
Almirante 3	1979	PS						0.08	0.1	0.23	0.19	0.16
Alturas	1980	PS						0	0.64	0.7	0.6	0.58
Pugnado Afuera 2	1980	PS						0	0.5	0.51	0.54	0.5
Coto Norte 3	1980	PS							0	0.12	0.13	0.14
Monserrate	1982	PS							0.35	0.7	1.11	0.66
Pugnado 3	1981	PS							0.12	0.23	0.16	0
Vega Baja 4	1984	PS								0	0.57	0.54
Ortho Lab	1984	Ind								0	0.02	0.07
Atenas	1984	PS								0.05	0.15	0.2
Sobrino	1983	PS								0.18	0.3	0.31
Coto Sur 5	1984	PS								0.23	0.38	0.32
Coto Sur 6	1984	PS								0.42	0.53	0.48
Algarrobo	1988	PS									0	0.7
Cruz Rosa-Rivas	1989	PS									0	0.25
Cordova Davilla	1989	PS									0.7	0.78
Villa Pinares	1989	PS									0	0.3
Escal Fullery	1989	PS									0	0.26
Arraiza	1991	PS									0	0.14
Total in Mgal/d			1.94	4.114	6.264	6.069	10.064	12.104	14.664	19.11	16.34	17.3

Model Calibration Process

The steady-state model was calibrated to assumed conditions and the observed potentiometric surface during March 1995 (Conde-Costas and Rodríguez, 1997). The heads in Laguna Tortuguero were set to the surveyed elevation of 0.9 ft above mean sea level for the river package. The lagoon outlet channel was simulated using river nodes with a change of head from 0.9 ft at the lagoon to 0.0 ft at the ocean (corresponding to mean sea level datum). The model calibration process required making adjustments to recharge values, first by changing the conversion factor in the recharge data-input matrix, and then by local adjustment of both transmissivity and recharge, until the following conditions were met: (a) model-generated heads and the potentiometric surface approximated those given in the hydrologic conditions of March 1995; (b) flux to cells representing springs (drain package) approximated observed flow rates in 1997; and (c) the flux to Laguna Tortuguero via direct discharge to the lagoon and nearby springs approximated the flow observed at the ocean outlet (50038200) in 1997.

During the steady-state model calibration process it was necessary to make some minor adjustments to modeled transmissivity input and recharge values. The final calibrated values for transmissivity were in general agreement with the areal distribution derived from specific-capacity data, and the aquifer flux was achieved with recharge of 18 in/yr or less, which is in general agreement with adjusted values for other areas previously modeled (figs. 17 and 18). The total net aquifer recharge simulated with the calibrated steady-state flow model of the upper aquifer was 35.9 ft^3/s. The ground-water budget for the Manatí to Vega Baja area, computed by Bennett and Giusti (1976), using the mass-balance approach, is 43.8 ft^3/s. Flow rates in the Laguna Tortuguero outlet channel and springs were also closely approximated, with the exception of Mameyes and several smaller springs in Barrio Tierra Nuevas, north of Manatí.

Riverbed conductance values were adjusted during the steady-state calibration process, in order to match low-flow measurements taken along the Río Grande de Manatí and the Río Indio. Discharge measurements made during the low-flow period in July 1997 were used in the comparison. The riverbed conductance values were adjusted along a section of the Río Grande de Manatí corresponding to model cells row 33, column 19, northward to row 28, column 19 (appendix 1). A simulated loss of 5.8 ft^3/s closely approximated the 5 ft^3/s low-flow river loss obtained on July 9, 1997. Several low-flow seepage runs were conducted along the Río Indio between the Highway PR-674 bridge (Río Arriba) and the overpass at Highway PR-22, south of the PRASA filtration plant. Although all flow measurements indicate a net river-gain for this stretch, measurements made on May 6, 1997, show a loss from the river to the aquifer of about 1 ft^3/s between row 27, column 61, and row 24, column 60. The steady-state model calibration for 1995 conditions indicates a streamflow loss of 1.0 ft^3/s to the aquifer for the river-reach north of Highway PR-674 to Highway PR-22, and a loss of 2.6 ft^3/s from the Río Cibuco, primarily in the river reaches south of Highway PR-2.

An instantaneous discharge measurement of 2.3 ft^3/s was obtained for the springs south of the lagoon near the inflow channel to Laguna Tortuguero during a relatively dry period in August 1997. The 1995 steady-state calibrated model output was 2.4 ft^3/s in cells representing the springs south of Laguna Tortuguero (table 2). The simulated discharge values for Ojo de Agua of 2.0 ft^3/s compared well with the range (1.4 to 5.9 ft^3/s) of discrete discharge measurements made between 1993 and 1996 (Rodríguez-Martínez, 1997). The simulated discharge values for Ojo de Guillo of 2.2 ft^3/s compared favorably with the 2.0 ft^3/s base flow established for the study of the Lower Río Grande de Manatí in 1984 (F. Gómez-Gómez, USGS, written commun., 1999).

The calibrated model heads were compared to actual conditions using the measured heads reported by Conde-Costas and Rodríguez (1997). The results indicate that 36 of a total of 37 control cell locations (water-level measurement sites) were calibrated within 10 ft of the measured heads. The difference between simulated and measured heads was greatest in the Coto Sur area, probably due to a relatively large model cell size compared to the steep head gradient in this area (appendix 2). South of latitude 18°25’, the low transmissivity values result in large fluctuations in aquifer heads over time and a steep gradient of the potentiometric surface. This is evident in observed water-level fluctuations of approximately 50 ft in the Perica observation well. Heads in six of the seven simulated wells were within 5 to 18 ft of the measured values in the area located between the Coto Sur area and the southern model boundary (fig. 19). In general, the difference between measured and simulated heads is less than 2 ft in the coastal plain north of Highway PR-2.

Simulated Change at Laguna Tortuguero 1940 to 1995

After the model was calibrated for steady-state conditions in March 1995, another steady-state simulation was used to document 1940 conditions, prior to dredging of the ocean outlet channel in 1943. The primary difference between the 1995 and 1940 model conditions were that for the 1940 model run, a water level of 3.3 ft above mean sea level was used for the river nodes representing the lagoon, and the three river nodes used to simulate the outlet channel to the sea were eliminated. Also, ground-water withdrawals for 1940 conditions were estimated to be 0.98 ft^3/s (0.63 Mgal/d). Adjustments to transmissivity values were not made, with the assumption that changes in the thickness of the freshwater lens in the coastal part of the aquifer were not great enough to alter the aquifer transmissivity estimates used in the steady-state model. A comparison of the 1940 simulation to the aquifer heads generated for March 1995 hydrologic conditions (Conde-Costas and Rodríguez, 1997) reveals the largest change in aquifer heads occurred in the Coto Sur area (well 78; fig. 5); heads changed from approximately 30 ft to less than 10 ft (figs. 20 and 21, respectively). The simulated heads for steady-state conditions for 1940 were used as initial heads for the three transient simulations. Because the majority of the ground-water development for the Manatí-Vega Baja area took place during the 1970's, the overall ground-water budget estimates of Giusti (1978) can be applied to the Manatí ground-water flow model for the upper aquifer steady-state 1940 conditions.

Aquifer outflows at springs, wetland areas, and river reaches in the coastal plains show a substantial decline from 1940 to 1995. The decreased outflows are attributed to increased ground-water withdrawals from a simulated rate of 0.98 ft^3/s during 1940 conditions, to 26.4 ft^3/s during 1995. The areal recharge values were the same for both simulations, but the increased ground-water withdrawals induced an additional 6.9 ft^3/s from river seepage, for an overall inflow of 48.6 ft^3/s.

Additional Calibration

Validation of the ground-water flow model was accomplished by simulating the historical trend of ground-water development in the area from 1943 to 1995. This transient simulation was divided into 10 stress periods of varying durations governed by substantial changes in pumpage (fig. 18). The results were compared to the head data obtained by Conde-Costas and Rodríguez (1997). The construction of the outlet channel of Laguna Tortuguero in 1943 was chosen as the initial date for the transient simulation. The aquifer heads from the steady-state 1940 simulation were used as the starting heads for the transient simulation, and the upper aquifer was assigned a storage coefficient of 0.10. The river-stage elevation and riverbed conductance remained constant throughout the simulation, with the exception of the stage estimates for Laguna Tortuguero, which were altered from a high of 3.3 ft (1 meter) pre-1943, 1.5 ft in 1975, and 0.9 ft above mean sea level in 1995. Also, riverbed conductance, transmissivities, and areal recharge remained constant throughout the transient simulation. Historical pumpage was reconstructed using available data from various sources, with the assumption that a given well started pumping from the construction date, unless available information indicated otherwise (table 3).

The aquifer heads for the 1995 transient simulation were slightly higher than the 1995 steady-state simulation, with an average absolute deviation from observed heads of 3.17 ft, compared to 3.10 ft for the steady-state model. The ground-water withdrawal rates for stress period 8 include four wells near the Río Cibuco reactivated as part of the Rice Irrigation Program; withdrawals from these wells totaled 3 Mgal/d (Fernando Gómez-Gómez, USGS, written commun., 1999). A comparison of the measured Laguna Tortuguero outflow (station number 50038200) to simulated values is shown in figure 22. A slight decline is evident in both the measured and the computed ground-water flux at the end of each stress period, which is attributed to increased ground-water withdrawals for the period of record.

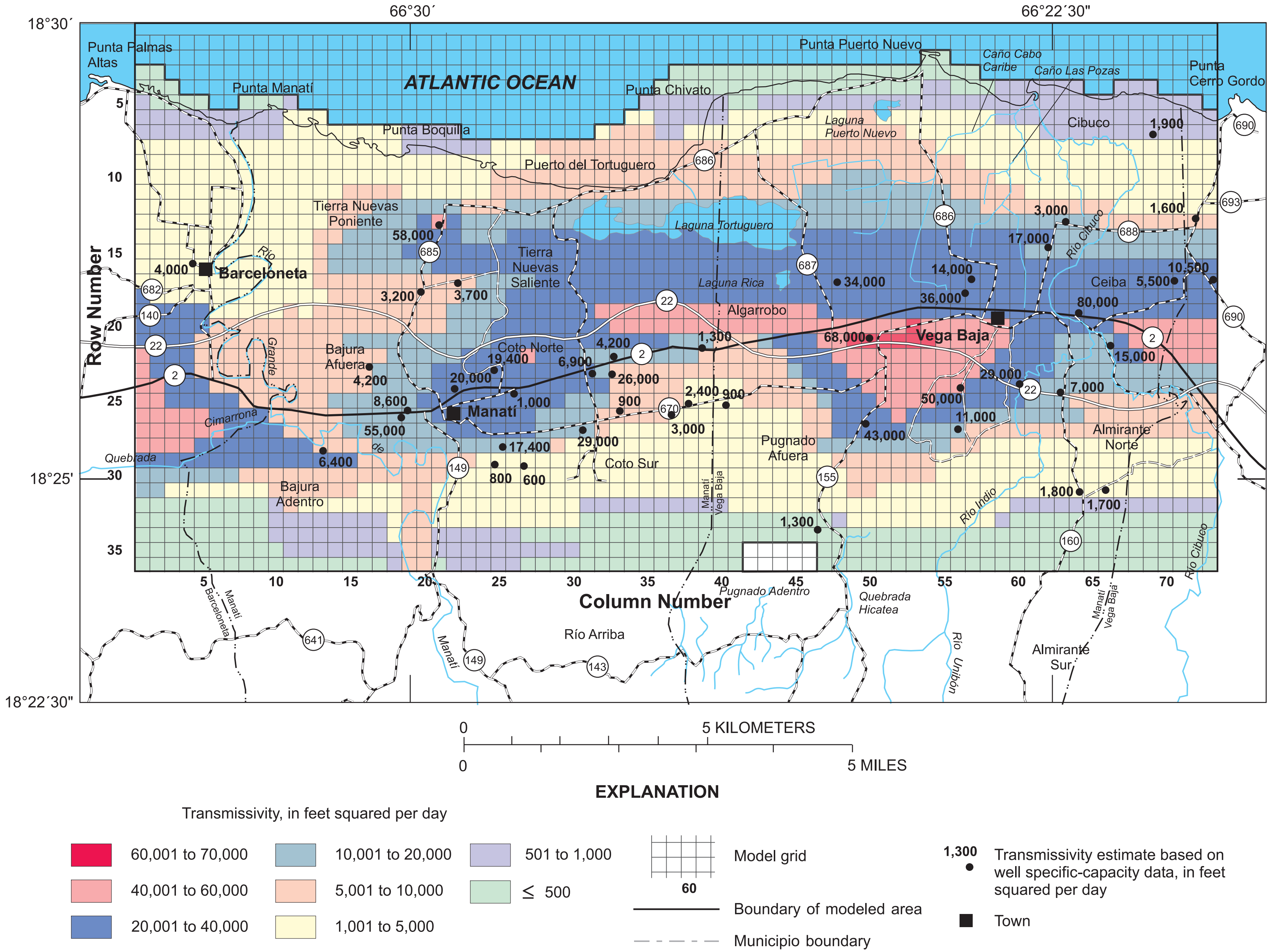


Figure 19. Calibrated transmissivity distribution for the digital ground-water flow model simulations of the upper aquifer in the Manatí-Vega Baja area, North Coast Province, Puerto Rico.

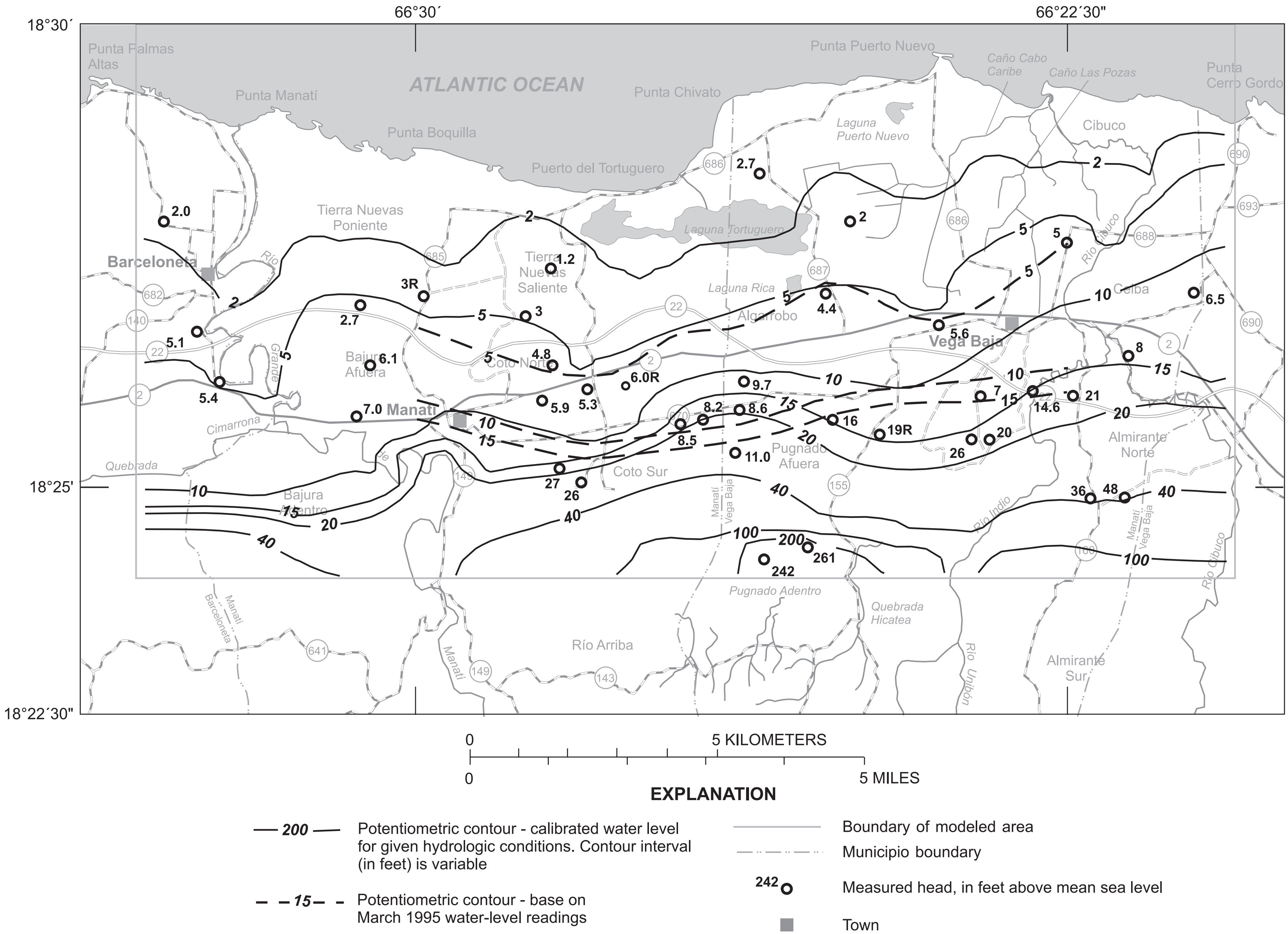


Figure 20. Simulated potentiometric surface for March 1995 steady-state conditions in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

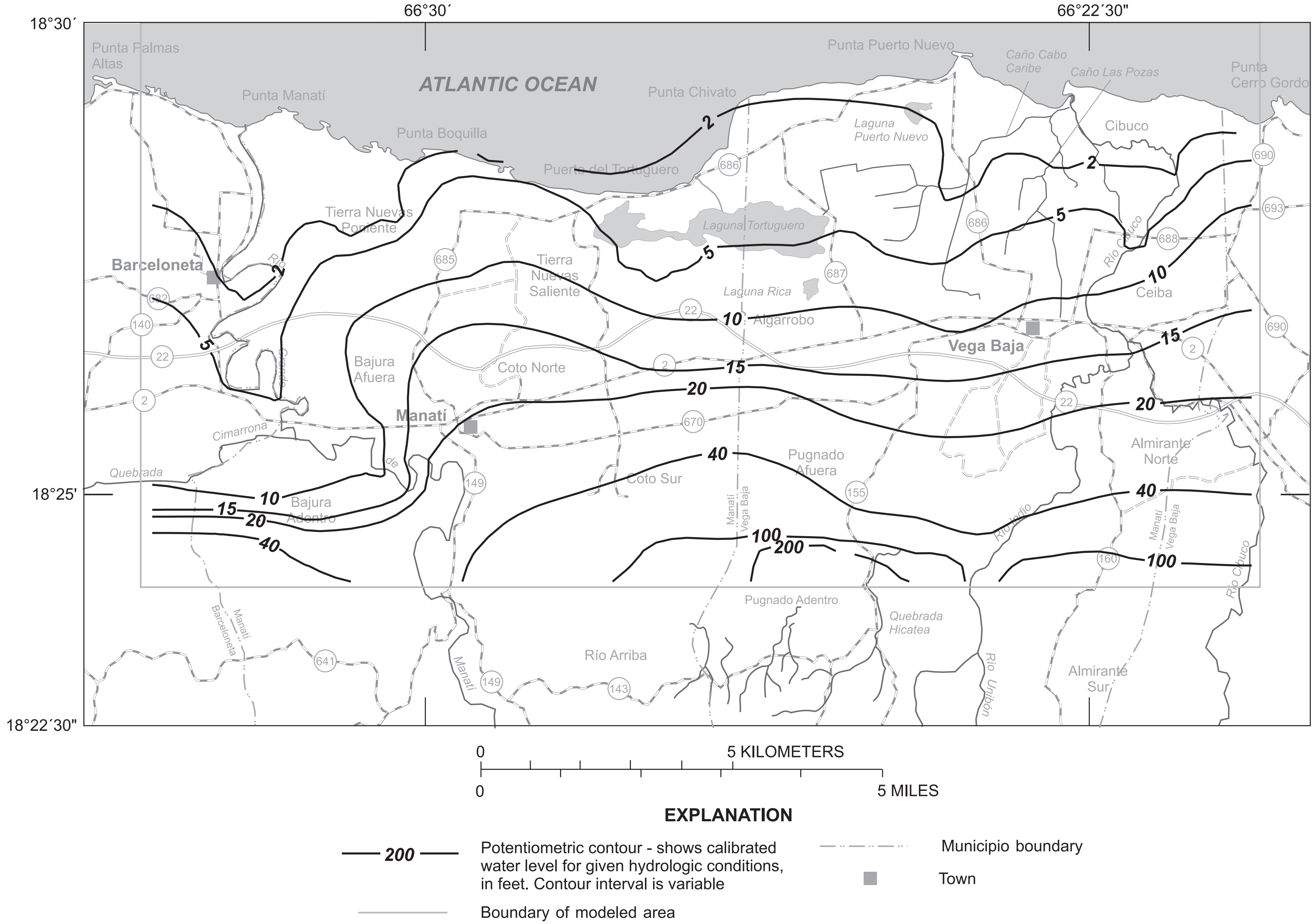


Figure 21. Simulated potentiometric surface for 1940 steady-state conditions in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico.

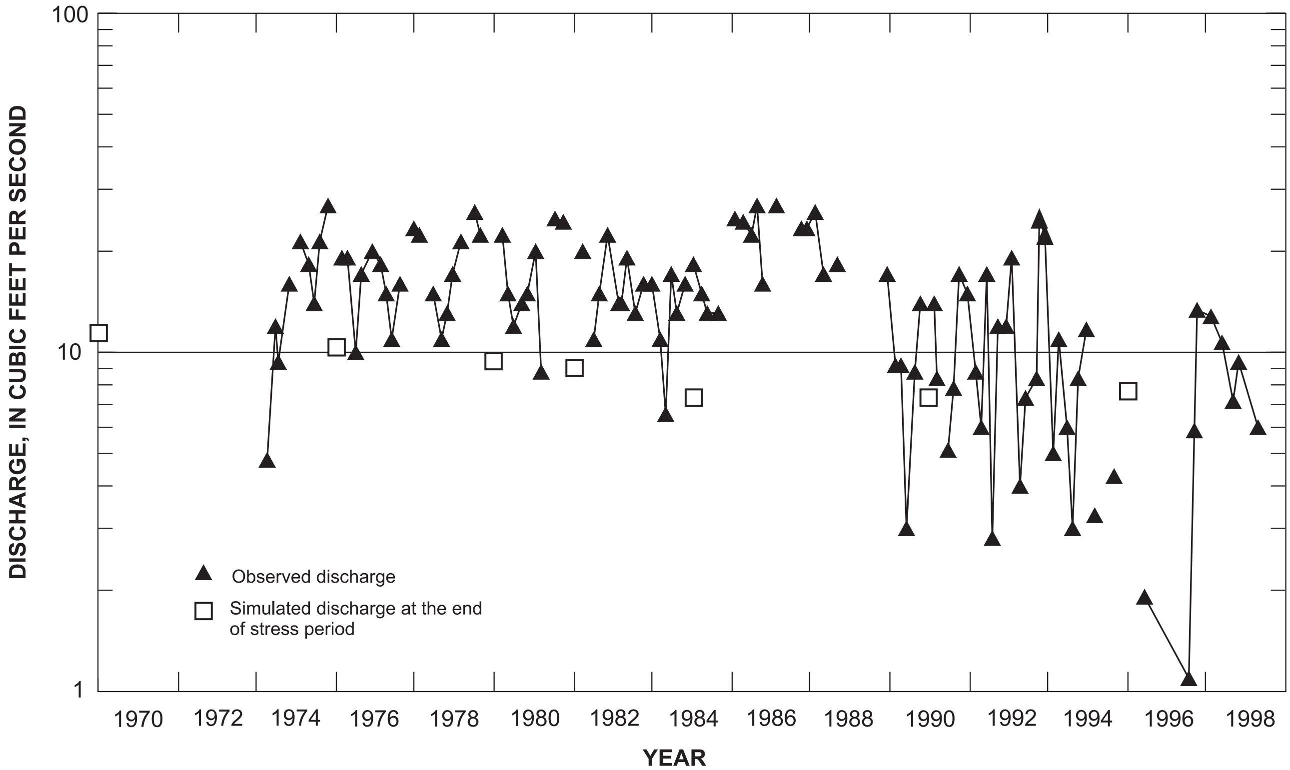


Figure 22. Comparison of measured and simulated discharge at Laguna Tortuguero outflow site.

Sensitivity Analysis

As with any model, there is uncertainty in the measurements of head (datum errors), transmissivity, estimation of recharge, and well withdrawal rates; therefore, it needs to be shown what effect there would be in a model if a parameter was not simulated properly. Moreover, each given input variable (transmissivity, riverbed conductance, recharge, and well pump rates) was adjusted during the calibration process to achieve a best fit of aquifer heads and fluxes, but the combination of parameters does not produce a unique solution. Therefore, values of transmissivity, recharge, ground-water withdrawals, and riverbed conductance, were factored separately by 0.25, 0.5, 0.75, 1.25, and 1.5 times, while the effects on the system were noted by observing changes in aquifer heads and water-budget components (appendixes 1 and 2). The mean residual or the accumulated deviation from the measured control cells was totaled and divided by the number of measurement sites for each recorded change.

The results of the sensitivity analysis show the ground-water model is slightly more sensitive to changes in transmissivity than changes in net recharge (fig. 23). When the input riverbed conductance values were increased by a factor of 10, the aquifer heads were altered only slightly, but the hydrologic budget increased from 45.8 to 54.9 ft^3/s, due to increased river seepage to the upper aquifer. Other parameters were also changed, using multipliers of 0.25, 0.5, 0.75, 1.25, and 1.5, and the results are presented in appendix 2 along with the percentage of heads that were within a given margin from the measured control nodes. In general, the aquifer heads in coastal areas were less sensitive to changes in transmissivity whereas heads in the upland areas south of Highway PR-2 were more sensitive, due to lower hydraulic conductivities and decreased aquifer thickness. Increasing transmissivity values from 1.25 to 2 times the calibrated values induced additional river flow into the aquifer ranging from approximately 1 to 4 ft^3/s.

Table 3. Comparison of simulated steady-state ground-water budgets for 1940 and March 1995 hydrologic conditions, Manatí-Vega Baja area, North Coast Province, Puerto Rico

[ft^3/s, cubic feet per second]

	1940 Simulated flow in ft^3/s	1995 Simulated flow in ft^3/s
Inflows:		
Quebradas Hicatea and El Salto, and Pugnado Adentro drainage area along southern boundary (injection wells)	1.61	1.61
River leakage into aquifer:		
Río Grande de Manatí	2.74	7.01
Río Cibuco	0.56	2.56
Río Indio	0.91	1.48
Total river leakage:	4.21	11.05
Recharge	35.93	35.93
Total inflows:	41.81	48.59
Outflows:		
Ground-water withdrawals	0.98	26.35
Springs:		
Springs - South of Laguna Tortuguero	5.93	2.37
Springs - Mameyes and Tierra Nueva	2.23	0.70
Spring - Ojo de Agua Vega Baja	6.75	2.05
Spring - Ojo de Guillo	2.45	2.21
Total springs:	17.36	7.33
River leakage out of aquifer:		
Caño Cabo Caribe	3.44	1.92
Caño Las Pozas	1.76	1.40
Laguna Tortuguero	4.00	2.86
Río Grande de Manatí	8.02	4.94
Río Indio	0.66	0.33
Río Cibuco	3.88	2.90
Atlantic Ocean	1.67	0.57
Total river leakage:	23.43	14.92
Total outflows:	41.77	48.60

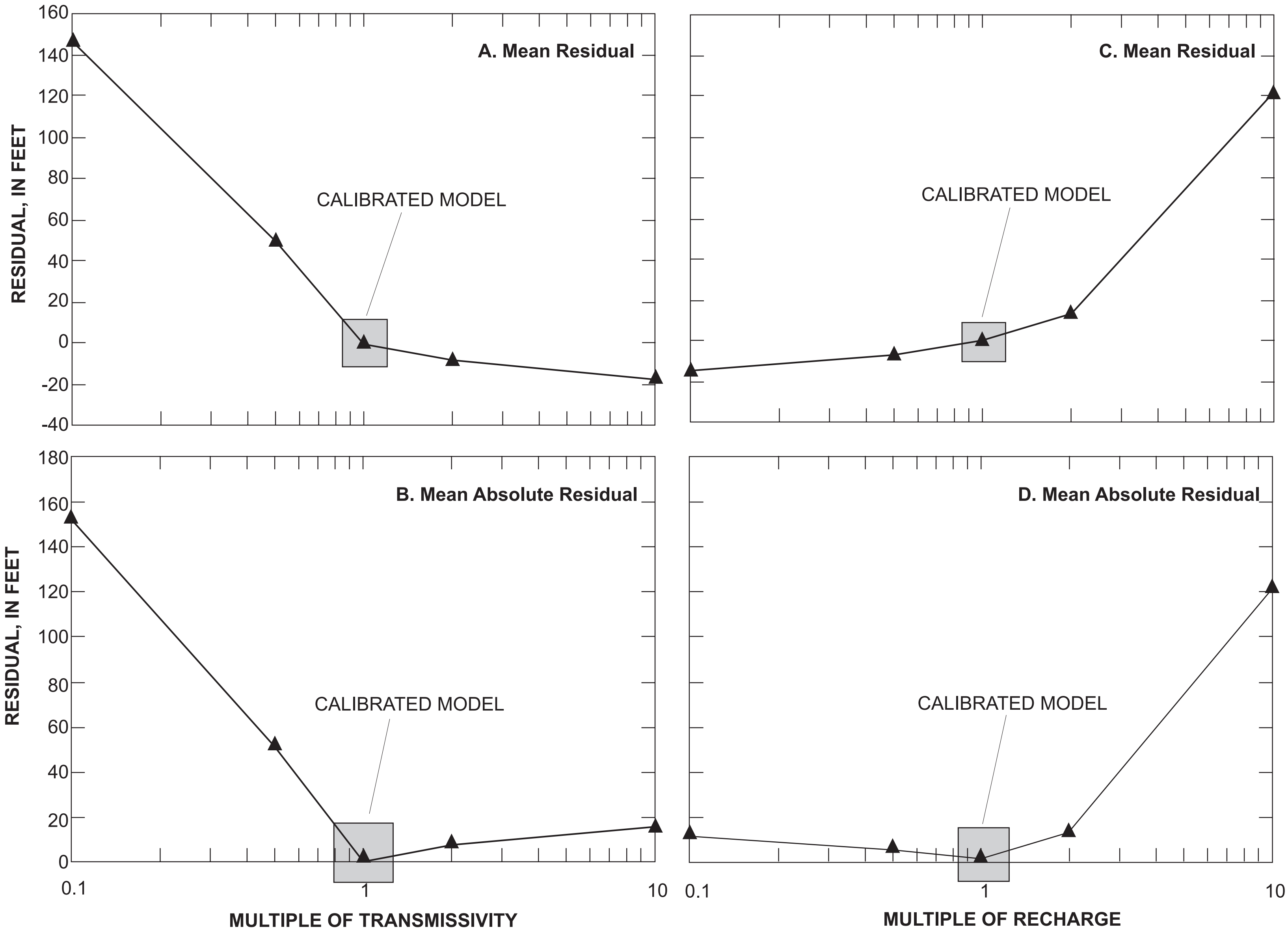


Figure 23. Sensitivity of model to changes in transmissivity and recharge.

Simulated Effects of Development

The increase in ground-water withdrawals in the upper aquifer between 1940 and 1995 had the effect of reducing ground-water discharge from springs, Laguna Tortuguero, and wetland areas while inducing additional recharge from the rivers into the aquifer (table 2). The depletion in aquifer storage in the Coto Sur area east of Manatí by increased ground-water withdrawals has lowered the aquifer head elevations from 30 to 10 ft during the same period (figs. 20 and 21, respectively).

Effect of Ground-Water Withdrawals on Hydrologic System

The total rate of ground-water withdrawals for 1940 conditions was estimated to be 0.98 Mgal/d, primarily along the coastal plain. In the late 1960's, the municipios constructed additional wells, and withdrawal rates increased to an estimated 6.1 Mgal/d (fig. 18). In the mid-1970's, a number of industries were established in the area that needed additional water supplies, and Vega Baja constructed several production wells, increasing total ground-water withdrawals to 10.1 Mgal/d. Data from the transient simulation show a substantial reduction in flow to springs at the end of stress period 4 (1970) attributed to increased ground-water withdrawals from the system. Increased ground-water withdrawals from three PRASA wells near Manatí (2.3 Mgal/d) in 1970 induced additional seepage from the Río Grande de Manatí. In the mid 1970's, the primary area of ground-water development was the Coto Sur area, between Highway PR-670 and Highway PR-2, with four production wells constructed to supply nearby industrial plants. Ground-water withdrawals in this area increased from 1.1 Mgal/d in 1970 to 3.0 Mgal/d in 1979, reaching a peak of 5.2 Mgal/d in 1984 before tapering off to 4.6 Mgal/d in 1990, due to several well closures. The effect on the aquifer was to lower the heads by as much as 18 ft through depletion of storage. According to output from the transient simulation, storage of the upper aquifer was depleted by 0.5 Mgal/d at the end of stress period 8 in 1984. Also during stress period 8 (1982-84), an additional 3 Mgal/d was pumped from four wells near the Río Cibuco, as part of a feasibility study to cultivate rice in the Río Cibuco valley. These wells were shut down at the conclusion of the study, but the construction of four PRASA public-supply wells in 1989 has maintained ground-water withdrawals at 17.3 Mgal/d.

Projected Changes in Ground-Water Withdrawals

The "Superaqueduct," when completed, will augment ground-water supplies by approximately 6 Mgal/d (F. Gómez-Gómez, USGS, written commun., 1999) to the municipios of Manatí and Vega Baja. The pipeline will transport approximately 75 Mgal/d of water from Lago Dos Bocas to communities along the north coast of Puerto Rico and the San Juan metropolitan area. The pipeline will pass through the municipios of Manatí and Vega Baja, along Highway PR-22 and supply water to the surrounding communities. Presumably, PRASA will close production wells having marginal water quality and place them on emergency (drought) stand-by status. A transient simulation was run to the year 2010, extending from the end of stress period 10 of the previously described transient simulation, and placing the projected withdrawal rates in three additional stress periods of varying duration (fig. 22). It is anticipated that well closures will occur gradually, until the pipeline is fully operational and integrated into the existing distribution system in 2005. Ground-water withdrawals are slightly higher for stress period 12 than those in stress periods 11 or 13, due to additional production wells along the western banks of the Río Grande de Manatí being placed on-line (capacity 2.3 Mgal/d). These wells (Cortez I and II) will supply the Cortez area and connect into the distribution system along Highway PR-2. The results of the transient simulation (fig. 24) show the 5-ft potentiometric contour moving north, and the aquifer heads in the Coto Sur area recovering to approximately 15 to 20 ft above mean sea level datum, with a 6-Mgal/d decrease in ground-water withdrawals. All springs in the wetland areas showed substantial increases in flow due to the decreased pumpage.

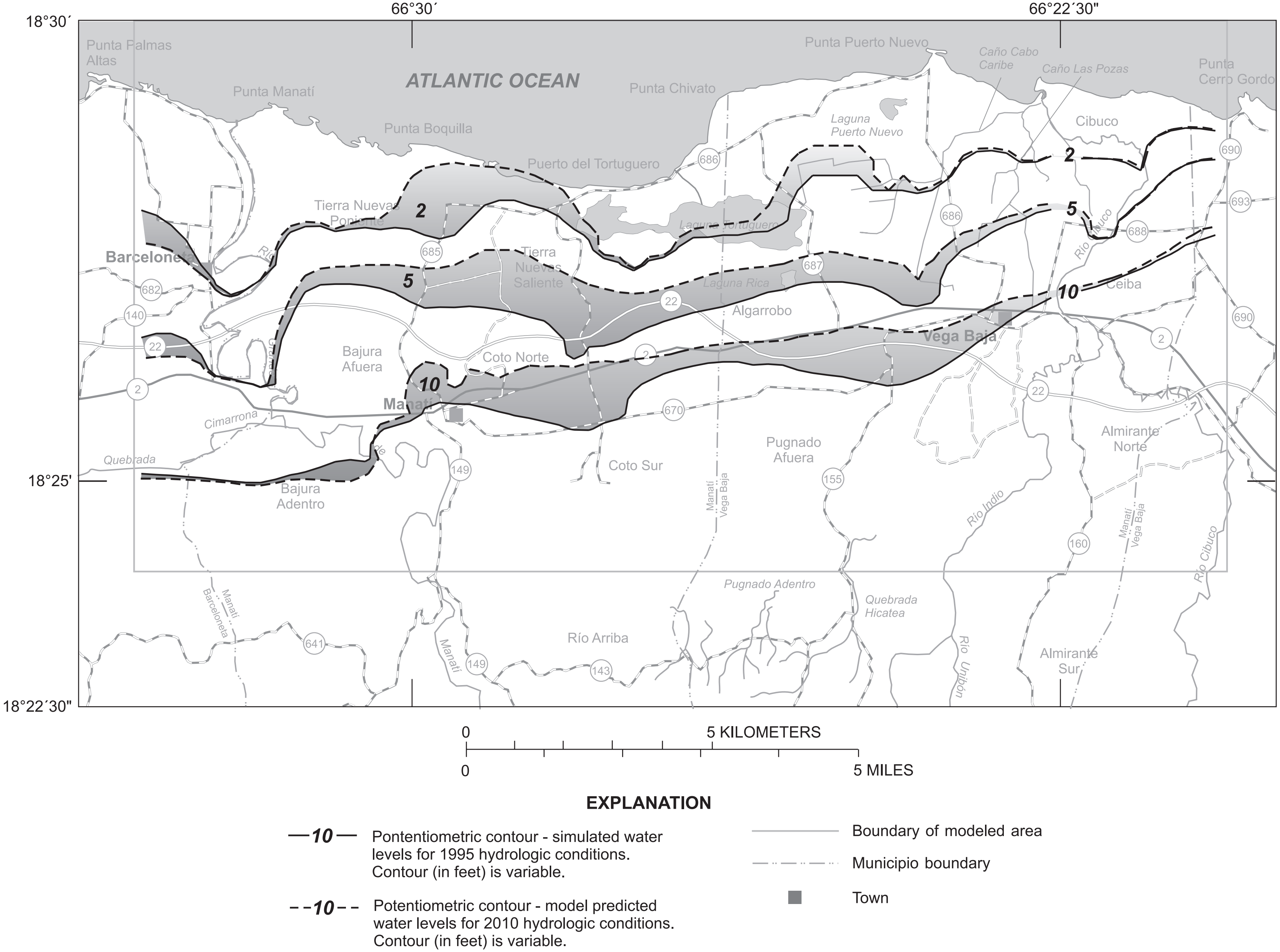


Figure 24. Simulated potentiometric surface from transient model runs using 1995 hydrologic conditions and predicted condition for 2010 in the Manatí-Vega Baja study area, North Coast Province, Puerto Rico (refer to figure 14 for withdrawal rates and stress periods).

MODEL LIMITATIONS AND ADDITIONAL DATA NEEDS

The construction of the Manatí ground-water flow model of the upper aquifer furthers our understanding of the hydrogeologic system. Large-scale changes can be anticipated, such as increased or decreased ground-water withdrawals over a given area. The calibration of the ground-water flow model can be considered a best-fit approximation of the known hydrologic parameters. Emphasis should be given to the leveling of long-term observation wells (Cantito La Luisa and Rosario 2) to improve inherent datum errors. Additional seepage runs should be conducted in specific areas along the Río Grande de Manatí and Río Indio to improve the accounting of gains and losses to the aquifer.

The constructed two-dimensional ground-water model does not have a moveable lower boundary, as occurs along the freshwater/saltwater interface. Improvements to the model could incorporate a package to simulate the freshwater/saltwater boundary, and use the results of tracer studies to define preferential ground-water flow paths to Laguna Tortuguero and nearby springs. Additional work should be conducted to inventory active domestic wells to improve the estimate of domestic ground-water withdrawals and to refine the hydrologic budget terms.

SUMMARY

A two-dimensional ground-water flow model of the Manatí area was constructed using the USGS computer program, MODFLOW, to simulate the effects of ground-water development and predict future changes to the Upper North Coast Limestone aquifer. Steady-state simulations were run for 1940 and for March 1995 to calibrate the model (because sufficient verifying data were available). The aquifer heads generated from the 1940 steady-state simulation were utilized to initiate a transient simulation with 10 stress periods up through 1995. The resulting heads were then used as initial conditions for a separate transient simulation that extended from 1995 to 2010 in order to predict the effect of the expected decrease in ground-water withdrawals on the ground-water system.

Findings from this investigation and model construction include:

1. Calibrated transmissivity values ranged from less than 500 ft^3/s, just north of the southern boundary, to about 70,000 ft^3/s, southwest of Vega Baja.
2. Model-calibrated aquifer recharge values ranged from 0 in/yr in the wetland areas of Cabo Caribe, to 4 in/yr in the alluvial valleys of Río Grande de Manatí and Río Cibuco, and 18 in/yr in sinkholes and areas of enclosed depressions.
3. Ground-water influx along the southern boundary of the model of 1.6 ft^3/s (injection wells) was based on flow measurements taken at Quebrada Hicatea over a 1-year period.
4. Volumetric budget terms for major ground-water flow components from 1940 steady-state simulation are:
    - areal recharge, 35.93 ft^3/s,
    - stream-flow infiltration into the aquifer along the central portion of the southern boundary of 1.61 ft^3/s, simulated as injection wells,
    - streamflow infiltration from losing river reaches, 4.21 ft^3/s,
    - discharge from springs south of Laguna Tortuguero, 5.93 ft^3/s,
    - discharge directly to Laguna Tortuguero, 4.00 ft^3/s,
    - discharge from other springs, 11.43 ft^3/s,
    - discharge to the wetland areas northeast of Laguna Tortuguero, 5.20 ft^3/s,
    - discharge to gaining river reaches, 12.56 ft^3/s,
    - discharge to the sea 1.67 ft^3/s,
    - discharge to pumping wells, 0.98 ft^3/s.

    The total calibrated ground-water flow was 41.77 ft^3/s.

5. Volumetric budget terms for major ground-water flow components for March 1995 steady-state simulation are:
    - areal recharge, 35.93 ft^3/s,
    - stream-flow infiltration into the aquifer along the central portion of the southern boundary, 1.61 ft^3/s, simulated as injection wells,
    - streamflow infiltration from losing river reaches, 11.05 ft^3/s,
    - discharge from springs south of Laguna Tortuguero, 2.37 ft^3/s,
    - discharge directly to Laguna Tortuguero, 2.86 ft^3/s,
    - discharge from other springs, 4.96 ft^3/s,
    - discharge to wetland areas northeast of Laguna Tortuguero, 3.32 ft^3/s,
    - discharge to gaining river reaches, 8.17 ft^3/s,
    - discharge to the sea, 0.57 ft^3/s,
    - discharge to pumping wells, 26.35 ft^3/s.

    The total calibrated ground-water flow was 48.60 ft^3/s.

6. Based on the results of the sensitivity analysis, transmissivity is the most sensitive parameter and riverbed conductance the least sensitive.
7. A transient simulation from 1943 to 2010 shows a decrease in ground-water withdrawals of 6 Mgal/d (9.3 ft^3/s), which produces a rise in aquifer heads and increase in ground-water discharge to springs and wetland areas.

SELECTED REFERENCES

Arnow, Ted, and Crooks, J.W., 1960, Public water supplies in Puerto Rico: U.S. Geological Survey Water-Resources Bulletin 2, 34 p.

Bennett, G.D., and Giusti, E.V., 1972, Ground water in the Tortuguero area, Puerto Rico, as related to proposed harbor construction: U.S. Geological Survey Water-Resources Bulletin 10, 25 p.

Briggs, R.P., 1966, The blanket sands of northern Puerto Rico, *in* 3rd Caribbean Geological Conference Transactions, Kingston Jamaica, 1962: Jamaica Geology Survey Publication 95, p. 60-69.

Brown, R.H., 1963, Estimating the transmissibility of a water-table aquifer from the specific capacity of a well, *in* Methods of determining permeability, transmissibility and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 332-336.

Colón, J.A., 1983, Algunos aspectos de la climatología de Puerto Rico: Acta Científica, v. 1, no. 2-3, p. 55-63.

Conde-Costas, Carlos, and Gómez-Gómez, Fernando, 1999, Assessment of nitrate contamination of the upper aquifer in the Manatí-Vega Baja area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 99-4040, 43 p.

Conde-Costas, Carlos, and Rodríguez, Gilberto, 1997, Potentiometric surface and hydrologic conditions of the upper aquifer in the Manatí-Vega Baja area, north-central Puerto Rico, March 1995: U.S. Geological Survey Water-Resources Investigations Report 96-4184, 1 pl.

Conde-Costas, Carlos, and Rodríguez-Rodríguez, G.A., 1997, Reconnaissance of ground-water quality in the Manatí quadrangle, Puerto Rico, August-November 1992: U.S. Geological Survey Open-File Report 96-628, 16 p.

Curtis, R.E., Jr., Aquino, Zaida, Díaz, P.L., and Vachier, R.J., 1991, Water resources data for Puerto Rico and the U.S. Virgin Islands, Water Year 1990: U.S. Geological Survey Water-Data Report PR-90-1, 514 p.

Curtis, R.E., Jr., Aquino, Zaida, Díaz, P.L., and Vachier, R.J., 1992, Water resources data for Puerto Rico and the U.S. Virgin Islands, Water Year 1991: U.S. Geological Survey Water-Data Report PR-91-1, 620 p.

Díaz, P.L., Aquino, Zaida, Figueroa-Alamo, Carlos, Vachier, R.J., and Sánchez, A.V., 1993, Water resources data for Puerto Rico and the U.S. Virgin Islands, Water Year 1992: U.S. Geological Survey Water-Data Report PR-92-1, 602 p.

Díaz, P.L., Aquino, Zaida, Figueroa-Alamo, Carlos, Vachier, R.J., and Sánchez, A.V., 1994, Water resources for Puerto Rico and the U.S. Virgin Islands, Water Year 1994: U.S. Geological Survey Water-Data Report PR-93-1, 516 p.

Díaz, P.L., Aquino, Zaida, Figueroa-Alamo, Carlos, Vachier, R.J., and Sánchez, A.V., 1995, Water resources for Puerto Rico and the U.S. Virgin Islands, Water Year 1995: U.S. Geological Survey Water-Data Report PR-94-1, 535 p.

Díaz, P.L., Aquino, Zaida, Figueroa-Alamo, Carlos, Vachier, R.J., and Sánchez, A.V., 1996, Water resources data for Puerto Rico and the U.S. Virgin Islands, Water Year 1992: U.S. Geological Survey Water-Data Report PR-92-1, 602 p.

Díaz, P.L., Aquino, Zaida, Figueroa-Alamo, Carlos, Vachier, R.J., and Sánchez, A.V., 1997, Water resources for Puerto Rico and the U.S. Virgin Islands, Water Year 1997: U.S. Geological Survey Water-Data Report PR-97-1, 548 p.

Díaz, P.L., Aquino, Zaida, Figueroa-Alamo, Carlos, Vachier, R.J., and Sánchez, A.V., 1998, Water resources for Puerto Rico and the U.S. Virgin Islands, Water Year 1998: U.S. Geological Survey Water-Data Report PR-98-1, 629 p.

Dopazo, Teresa, and Molina-Rivera, W.L., 1995, Estimated water use in Puerto Rico, 1988-89: U.S. Geological Survey Open-File Report 95-380, 31 p.

Geraghty & Miller, Inc., 1992, A ground-water flow and transport model of the Vega Alta area: v. 1-2.

Gillette, S.M., Vogel, J.L., and Julian, L.T., 1996, Precipitation frequency study for Puerto Rico and the Virgin Islands, Second progress report: Office of Hydrology, National Weather Service, 20 p.

Giusti, E.V., 1978, Hydrogeology of the karst of Puerto Rico: U.S. Geological Survey Professional Paper 1012, 68 p.

Giusti, E.V., and Bennett, G.D., 1976, Water resources of the North Coast Limestone area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 42-75, 42 p.

Gómez-Gómez, Fernando, 1984, Water resources of the lower Río Grande de Manatí valley, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 83-4199, 42 p.

Gómez-Gómez, Fernando, Quiñones, Ferdinand, and López, Marisol, 1984, Public water supplies in Puerto Rico, 1983: U.S. Geological Survey Open-File Report 84-126, 102 p.

Gómez-Gómez, Fernando, and Torres-Sierra, Heriberto, 1988, Hydrology and effects of development on the water-table aquifer in the Vega Alta quadrangle, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 87-4105, 54 p.

Guzmán-Ríos, Senén, 1988, Hydrology and water quality of the principle springs in Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 85-4269, 30 p.

Harbaugh, A.W., and McDonald, M.G., 1997, User's documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow model: U.S. Geological Survey Open-File Report 96-485, 56 p.

Heisel, J.E., González J.R., and Cruz, Carlos, 1983, Analog model analysis of the North Coast Limestone aquifer, Puerto Rico: U.S. Geological Survey Open-File Report 82-52, 49 p.

Kuniansky, E.L., and Holligan, K.Q., 1994, Simulations of flow in the Edwards-Trinity Aquifer System and contiguous hydraulically connected units, west-central Texas: U.S. Geological Survey Water-Resources Investigations Report 93-4039, 40 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 6, Chapter A1, 586 p.

McGuiness, C.L, 1946, Records of wells in Puerto Rico: Puerto Rico Aqueduct and Sewer Service in cooperation with U.S. Geological Survey, 267 p.

McGuinness, C.L., 1948, Ground-water resources of Puerto Rico: U.S. Geological Survey Open-File Report, 613 p.

Meyerhoff, H.A., and Frazier, J.E., 1945, Glass sand and a glass industry in Puerto Rico: Mining Technology, v. 9, no. 6, 9 p.

Molina-Rivera, W.L., 1998, Estimated water use in Puerto Rico, 1995: U.S. Geological Survey Open-File Report 98-276, 28 p.

Molina-Rivera, W.L., and Dopazo, Teresa, 1995, Estimated water use in Puerto Rico, 1986-87: U.S. Geological Survey Open-File Report 95-358, 31 p.

Monroe, W.H., 1962, Geologic map of the Manatí quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-334, 1 sheet, scale 1:20,000.

Monroe, W.H., 1971, Geologic map of the Manatí quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-671, 1 sheet, scale 1:20,000.

Monroe, W.H., 1976, The karst landforms of Puerto Rico: U.S. Geological Survey Professional Paper 899, 69 p.

Monroe, W.H., 1980, Geology of the middle Tertiary Formations of Puerto Rico: U.S. Geological Survey Professional Paper 953, 93 p., 1 pl., scale 1:250,000.

Quiñones-Aponte, Vicente, 1986, Water resources of the lower Río Grande de Arecibo alluvial valley, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 86-4160, 38 p.

Quiñones-Marquéz, Ferdinand, and Fusté, L.A., 1978, Limnology of Laguna Tortuguero, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 77-122, 86 p.

Ramos-Ginés, Orlando, 1997, Water balance and quantification of total phosphorus and total nitrogen loads entering and leaving Lago de Cidra, central Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 96-4222, 28 p.

Renken, R.A., and Gómez-Gómez, Fernando, 1994, Potentiometric surfaces of the upper and lower Aquifers, North Coast Limestone aquifer system, Puerto Rico: U.S. Geological Survey Open-File Report 93-499, 16 p.

Rodríguez-Martínez, Jesús, 1991, The hydrogeologic framework of the North Coastal aquifer system of Puerto Rico, *in* Gómez-Gómez, Fernando, Quiñones-Aponte, Vicente, and Johnson, A.I., eds., Aquifers of the Caribbean Islands: American Water Resources Association Monograph 15, p. 5-16.

Rodríguez-Martínez, Jesús, 1995, Hydrogeology of the North Coast Limestone aquifer system of Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 94-4249, 22 p.

Rodríguez-Martínez, Jesús, 1997, Characterization of springflow in the North Coast Limestone of Puerto Rico using physical, chemical, and stable isotopic methods: U.S. Geological Survey Water-Resources Investigations Report 97-4122, 53 p.

Rodríguez-Martínez, Jesús, Scharlach, R.A., and Torres-González, Arturo, 1992, Geologic and hydrologic data collected at test holes NC-4 and NC-14, Manatí and Vega Baja, Puerto Rico: U.S. Geological Survey Open-File Report 92-126, 32 p.

Santiago-Rivera, Luis, 1998, Low-flow characteristics at selected sites on streams in northern and central Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 98-4200, 53 p.

Seiglie, G.A., and Moussa, M.T., 1984, Late Oligocene-Pliocene transgressive-regressive cycles of sedimentation in northwestern Puerto Rico, *in* Schlee, J.S., ed., Interregional unconformities and hydrocarbon accumulation: American Association of Petroleum Geologists Memoir 36, p. 89-98.

Theis, C.V., Brown, R.H., and Meyer, R.R., 1963, Estimating the transmissivity of a water-table aquifer from the specific capacity of a well, *in* R. Bentall, ed., Methods of determining permeability, transmissibility and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 331-341.

Torres-González, Arturo, 1985, Simulation of ground-water flow in the water-table aquifer near Barceloneta, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 84-4113, 39 p.

Torres-González, Arturo, and Díaz, Raul, 1985, Water resources of the Sebana Seca to Vega Baja area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 82-4115, 53 p.

Torres-González, Arturo, and Wolansky, R.M., 1984, Planning report for the comprehensive appraisal of the ground-water resources of the North Coast Limestone area of Puerto Rico: U.S. Geological Survey Open-File Data Report 84-427, 32 p.

Torres-González, Sigfredo, 1991, Compilation of ground-water level measurements obtained by the U.S. Geological Survey in Puerto Rico, 1958-1985: U.S. Geological Survey Open-File Data Report 88-701, 163 p.

Torres-González, Sigfredo, Planert, Michael, and Rodríguez, J.M., 1996, Hydrogeology and simulation of ground-water flow in the upper aquifer of the Río Camuy to Río Grande de Manatí area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 95-4286, 102 p.

Torres-Sierra, Heriberto, 1985, Potentiometric surface of the upper limestone aquifer in the Dorado-Vega Alta area, north-central Puerto Rico, February 1983: U.S. Geological Survey Water-Resources Investigations Report 85-4268, 1 sheet, scale 1:20,000.

Torres-Sierra, Heriberto, and Avilés, Ada, 1986, Estimated water use in Puerto Rico, 1980-82: U.S. Geological Survey Open-File Report 85-557, 77 p.

Tucci, Patrick, and Martínez, M.I., 1995, Hydrology and simulation of ground-water flow in the Aguadilla to Río Camuy area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 95-4028, 39 p.

U.S. Census Bureau, Population Division, Population Studies Branch: accessed March 13, 2001 at http://www.census.gov/population/www/estimates/puerto-rico.html.

U.S. Department of Commerce, 1991, 1990 census of population and housing characteristics, Puerto Rico: U.S. Department of Commerce, Economics and Statistics Administration, Bureau of Census, 1990-CHP-1-53.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1982, Climatography of the United States No. 60, Climate of Puerto Rico and Virgin Islands: 25 p.

Ward, W.C., Sharlach, R.A., and Hartley, J.R., 1991, Controls on porosity and permeability in subsurface Tertiary carbonate rocks of northern Puerto Rico, *in* Gómez-Gómez, Fernando, Quiñones-Aponte, Vicente, and Johnson, A.I., eds., Aquifers of the Caribbean Islands: American Water Resources Association Monograph 15, p. 17-23.

Zapp, A.D., Bergquist, H.R., and Thomas, C.R., 1948, Tertiary geology of the coastal plains of Puerto Rico: U.S. Geological Survey Oil and Gas Investigations Preliminary Map OM-85, 2 sheets, scale 1:60,000.

APPENDIXES

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer. Steady-state simulation for hydrologic conditions of March 1995.

```
BASIC INPUT PACKAGE
         1         36         73          1         1
11  8  3 23  0  0  0 18 17  0  0  0 23  0  0  0  0  0  0  0  0  0  0  0
         0          0
         5          1 (20I3)                                4
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 /* 01
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 /* 02
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0
  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 /* 03
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0
  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 /* 04
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  0  0  1  1  1  0  0  0  0
  1  1  1  1  1  0  0  1  1  1  1  0  0  0  0  0  0  0  0  0 /* 05
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  0
  1  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0 /* 06
  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  3  3  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 /* 07
  1  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  3  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  3  3  1  1  1  1  1  1  1  1  1  1  1  1 /* 08
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  3  3  3  3  3  1  1  1  1  1  1
  1  1  1  1  1  1  1  3  1  1  1  1  1  1  1  1  1  1  1  1 /* 09
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  4  4  1  1  1  1
  1  1  1  1  1  1  1  3  1  1  1  1  1
  1  1  1  1  1  1  1  3  1  1  1  1  1  1  1  1  1  1  1  1 /* 10
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  4  4  1  1  1  1
  1  1  1  1  1  1  1  3  1  1  1  1  1
  1  1  1  1  1  1  1  3  1  1  1  1  1  1  1  1  1  1  1  1 /* 11
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  2  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  3  3  1  1  1  1  1
  1  1  1  1  1  1  1  3  1  1  1  1  1  1  1  1  1  1  1  1 /* 12
  1  1  1  1  1  1  1  1  1  1  2  2  2  1  1  1  2  2  2  2
  2  2  2  2  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  3  3  1  1  1  1  4  4
  1  1  1  1  1  1  1  3  1  1  1  1  1  1  1  1  1  1  1  1 /* 13
  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2
  2  2  2  2  2  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  3  1  1  4  4  1  1  1
  1  1  1  1  1  1  3  1  1  1  1  1  1  1  1  1  1  1  1  1 /* 14
  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2
  2  2  2  2  2  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  3  3  1  1  4  4  4  4  1
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
  1  1  1  1  4  3  1  3  3  1  1  1  1  1  1  1  1  1  1  1 /* 15
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  2  2  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  3  3  1  1  1  1  1  1  1  1
  1  1  1  1  4  3  3  1  1  3  1  1  1  1  1  1  1  1  1  1 /* 16
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  4  4  4  1
  1  1  3  3  1  1  1  1  1  1  1  1  1
  1  1  4  4  4  1  1  1  3  1  1  1  4  4  4  1  1  1  1  1 /* 17
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  4  4  1  1  1  1  1  1  1  1  1  1  1  1  1  4  4  4  1
  1  3  3  1  1  1  1  1  1  1  1  1  1
  1  1  4  4  4  3  3  3  1  1  1  1  4  4  4  4  1  1  1  4 /* 18
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  5
  5  4  4  1  1  1  1  1  1  4  4  1  4  4  1  4  4  4  4  1
  1  3  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  3  3  1  1  1  1  1  1  1  4  4  1  1  4  4  4 /* 19
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  5  5  1  1  1  1  1  1  1  1  4  4  4  1  4  4  4  4  4  4
  1  3  3  1  1  1  1  1  1  4  4  4  4
 10 10 10 10  3  3  3 10 10 10 10 10 10 10 10 10 10 10  4 10 /* 20
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10  4  4 10 10 10 10  4  4  4
 10 10 10  3  3 10 10 10 10  4  4 10 10
  4 10 10 10 10  3  3  3  3 10 10 10 10 10 10 10 10 10  4 10 /* 21
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  4  4  4  4  4
  4  4 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  4
 10 10 10 10  3  3  4  4 10  4  4 10 10
 10 10 10 10 10  3 10  3  3 10 10 10 10 10 10 10 10  4 10 10 /* 22
 10 10 10  4 10 10  9  9  9  9  9  9  9  9  9  9  9  9  9  9
 10 10 10 10 10 10 10 10 10 10  4  4 10 10 10 10 10 10 10  4
 10 10  3  3  3  3  4  4  4  4  4 10 10
 10  4  4  4  4  3  3  3  3 10 10 10 10 10 10 10 10 10 10 10 /* 23
 10 10 10  4  4  4  9  9  9  9  9  9  9  9  9  9  9  9  9  9
 10 10 10  4  4 10 10 10 10 10  4  4  4  4  4  4  4  4  4  4
  3  3  3  4 10 10  3  4  4  4  4 10 10
  4  4 10 10 10 10 10 10  3  3  3 10 10 10 10 10 10 10 10  4 /* 24
  4  4  4  4  4  4  9  9  9  9  9  9  9  9  9  9  9  9  9  9
 10  4  4  4  4 10 10 10 10  4  4  4  4  4  4  4  4  4  4  3
  3 10  4  4 10 10  3 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10  3  3 10 10 10 10 10 10 10 10 10 /* 25
  4  4  4  4  4  4  9  9  9  9  9  9  9  9  9  9  9  9  9  9
 10 10  4 10 10 10 10  4  4  4  4 10 10 10 10 10 10 10  4  3
 10 10 10 10 10 10  3  3  3  3  3  3 10
 10 10 10 10 10 10 10 10 10  3  3 10 10  3  3  3 10 10 10  4 /* 26
  4  4  4  4  4  4  9  9  9  9  9  9  9  9  9  9  9  9  9  9
  6  6  4 10 10 10 10  4  4  4  4 10 10 10 10 10 10 10  4  3
 10 10  4 10 10 10 10 10 10 10 10  3 10
 10 10 10 10 10 10 10 10 10 10  3  3  3  3 10  3 10 10 10 10 /* 27
  4  4  4  4  4  4  9  9  9  9  9  9  9  9  9  9  9  9  9  9
  6  6  6  6  6  6  6  6 10 10  4  4  4  4  4  4  4  4  4  3
  3  3  4  4 10 10 10 10 10 10 10  3 10
 10 10 10 10 10 10 10 10 10 10 10  3  3 10 10  3 10  3  3  3 /* 28
  3 10  4  4  4  4  9  9  9  9  9  9  9  9  9  9  9  9  9  9
 10 10 10 10 10 10 10 10 10 10  4  4  4  4  4  4  4 10 10 10
 10  3 10 10 10 10 10 10 10 10 10  3  3
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3  3  3 10 10 /* 29
  3 10 10 10  4  4  9  9  9  9  9  9  9  9  9  9  9  9  9  9
  6  6  6  6 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
  3  3 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3  3 10 10 /* 30
  3 10 10 10  4 10  9  9  9  9  9  9  9  9  9  9  9  9  9  9
  6  6  6  6 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
  3  3 10 10 10 10 10 10  4  4 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 /* 31
  3 10 10 10  4 10  4 10  6 10  6  6  6 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3  3
 10 10 10  4 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3  3 /* 32
  3 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3  3 10
 10 10 10  4 10 10 10 10 10 10 10 10 10
 10 10 10 10  4  4  4 10 10 10 10 10 10 10 10 10 10 10  3 10 /* 33
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10  4  4  4 10 10 10 10 10 10 10 10 10 10  3 10 10 /* 34
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3  3 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3 10 /* 35
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 10  0  0  0  0  0 10 10 10 10 10 10 10 10  3  3 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  3 10 /* 36
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 10  0  0  0  0  0 10 10 10 10 10 10 10 10  3 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10 10
         0
         5       1.0(10F7.2)                   -1
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00
   0.56   0.55   0.54   0.57   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.50   0.50   0.50   0.50
   0.50   0.50   0.50   0.50   0.50   0.50   0.50   0.50   0.50   0.50
   0.51   0.51   0.51   0.51   0.51   0.50   0.50   0.50   0.50   0.50
   0.50   0.50   0.50   0.50   0.50   0.51   0.51   0.51   0.51   0.51
   0.51   0.52   0.52
   1.19   1.10   0.94   0.60   0.55   0.52   0.49   0.46   0.43   0.41
   0.41   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.50   1.02   1.24   1.33   1.38
   1.36   1.36   1.39   1.37   1.35   1.31   1.27   1.23   1.19   1.15
   1.10   1.05   0.99   0.95   0.90   0.82   0.74   0.67   0.62   0.59
   0.58   0.62   0.68   0.76   0.86   0.97   1.11   1.27   1.44   1.60
   1.74   1.83   1.88
   1.66   1.55   1.37   1.11   0.89   0.66   0.42   0.16  -0.09  -0.27
  -0.29   0.17   0.21   0.24   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.50   1.25   1.73   1.99   2.10   2.14
   2.11   2.09   2.12   2.09   2.03   1.96   1.89   1.82   1.75   1.67
   1.58   1.48   1.37   1.25   1.16   1.06   0.93   0.80   0.70   0.64
   0.62   0.69   0.82   0.97   1.15   1.36   1.62   1.93   2.26   2.57
   2.84   3.03   3.13
   2.04   1.95   1.76   1.49   1.16   0.79   0.37  -0.08  -0.54  -0.95
  -1.26  -1.40  -1.46  -1.22  -0.20  -0.01   0.11   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.50   1.55   2.00   2.38   2.59   2.66   2.67
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
  2.66    2.62    2.57    2.51    2.43    2.33    2.24    2.15    2.06    1.97
  1.86    1.74    1.60    1.46    1.33    1.19    1.04    0.85    0.72    0.63
  0.57    0.71    0.91    1.11    1.34    1.62    1.97    2.41    2.90    3.37
  3.76    4.03    4.17
  2.39    2.32    2.13    1.83    1.43    0.93    0.35   -0.28   -0.94   -1.60
 -2.21   -2.74   -3.10   -3.13   -2.79   -2.35   -1.62   -0.26    0.11    0.30
  0.42    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  0.00    0.00    0.50    1.75    2.37    2.68    3.07    3.22    3.17    3.06
  2.98    2.90    2.80    2.71    2.60    2.49    2.38    2.29    2.19    2.09
  1.98    1.86    1.72    1.57    1.44    1.28    1.11    0.80    0.69    0.60
  0.60    0.66    0.98    1.21    1.46    1.77    2.18    2.77    3.47    4.12
  4.64    5.01    5.20
  2.77    2.67    2.46    2.14    1.71    1.13    0.39   -0.40   -1.23   -2.11
 -3.06   -3.99   -4.72   -5.10   -5.07   -4.59   -3.66   -2.40   -1.32   -0.43
  0.23    0.61    0.75    0.76    0.50    0.50    0.50    0.50    0.50    0.50
  0.50    0.50    1.81    2.63    3.08    3.53    3.87    3.85    3.60    3.29
  3.11    3.01    2.91    2.81    2.69    2.55    2.44    2.34    2.24    2.12
  2.00    1.88    1.75    1.62    1.50    1.32    1.23    1.13    1.03    0.80
  0.87    0.86    1.15    1.31    1.51    1.80    2.20    3.01    4.03    4.92
  5.61    6.08    6.31
  3.17    3.05    2.81    2.44    1.95    1.32    0.55   -0.34   -1.38   -2.52
 -3.78   -5.05   -6.17   -6.99   -7.25   -6.73   -5.55   -3.93   -2.27   -0.81
  0.33    1.14    1.67    1.97    1.99    2.05    2.14    2.25    2.37    2.46
  2.56    2.76    3.27    3.71    4.00    4.39    4.54    4.36    3.91    3.32
  3.14    3.09    3.01    2.91    2.79    2.58    2.48    2.41    2.32    2.12
  2.01    1.89    1.75    1.63    1.54    1.55    1.55    1.51    1.39    1.09
  1.13    1.52    1.39    1.36    1.46    1.71    1.97    3.14    4.60    5.78
  6.61    7.17    7.45
  3.60    3.47    3.20    2.81    2.27    1.59    0.76   -0.22   -1.40   -2.74
 -4.27   -5.91   -7.52   -8.84   -9.38   -8.74   -7.21   -5.00   -2.74   -0.81
  0.67    1.73    2.48    3.02    3.20    3.33    3.50    3.73    3.97    4.12
  4.22    4.34    4.55    4.79    4.94    5.17    5.16    4.92    4.37    3.09
  3.05    3.17    3.12    3.02    2.99    2.52    2.51    2.50    2.48    2.03
  2.00    1.91    1.74    1.60    1.51    1.69    1.79    1.82    1.76    1.62
  1.79    2.39    2.70    2.89    3.07    3.21    3.23    3.11    5.22    6.65
  7.59    8.21    8.54
  4.08    3.94    3.66    3.24    2.68    1.96    1.08    0.03   -1.25   -2.77
 -4.57   -6.66   -8.92  -10.93  -12.07  -11.08   -9.07   -5.85   -2.80   -0.39
  1.31    2.46    3.29    3.88    4.14    4.33    4.58    4.92    5.38    5.51
  5.55    5.56    5.58    5.63    5.63    5.65    5.56    5.39    5.11    4.72
  4.26    3.31    3.20    3.04    3.02    3.01    2.89    2.71    2.49    2.26
  2.01    1.98    1.70    1.51    1.53    1.89    2.04    2.07    2.07    2.13
  2.63    3.22    3.68    4.06    4.30    4.37    4.22    3.93    6.22    7.70
  8.66    9.23    9.62
  4.63    4.48    4.19    3.76    3.18    2.43    1.52    0.43   -0.91   -2.53
 -4.56   -7.17  -10.14  -13.16  -15.71  -13.59  -11.37   -6.35   -2.32    0.48
  2.23    3.24    3.98    4.55    4.85    5.11    5.40    5.79    6.20    6.21
  6.18    6.12    6.05    5.97    5.89    5.79    5.68    5.52    5.33    5.08
  4.79    4.46    4.19    3.93    3.45    3.53    3.29    2.95    2.52    2.47
  2.02    1.89    1.55    1.56    2.04    2.28    2.32    2.29    2.26    2.49
  3.23    3.94    4.53    5.01    5.28    5.27    4.98    5.40    7.72    9.06
  9.86   10.14   10.76
  5.24    5.10    4.80    4.36    3.76    3.01    2.09    0.99   -0.32   -1.94
 -3.99   -6.70  -10.45  -14.86  -21.58  -15.15  -14.98   -5.88   -1.14    1.66
  3.07    3.76    4.42    5.03    5.41    5.74    5.99    6.21    6.32    6.31
  6.26    6.19    6.11    6.03    5.94    5.84    5.73    5.59    5.43    5.22
  4.99    4.74    4.47    4.17    3.75    4.00    3.73    3.23    2.70    2.49
  2.02    2.01    2.25    2.49    2.70    2.74    2.57    2.47    2.19    2.83
  3.76    4.60    5.28    5.81    6.10    6.00    6.54    8.12    9.51   10.47
 11.04   11.44   11.96
  5.94    5.79    5.48    5.03    4.43    3.68    2.78    1.72    0.49   -1.00
 -2.87   -5.28   -8.55  -12.15  -17.04  -10.92   -7.08   -2.80    0.54    2.48
  3.40    3.99    4.70    5.40    5.92    6.28    6.46    6.50    6.46    6.42
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
  6.35   6.26   6.17   6.08   5.99   5.90   5.81   5.69   5.54   5.37
  5.19   4.99   4.79   4.57   4.38   4.38   4.14   3.52   2.57   2.49
  2.04   2.08   2.88   3.28   3.43   3.27   2.71   2.72   2.99   2.97
  4.16   5.11   5.87   6.46   6.88   7.23   8.49   9.71  10.71  11.44
 11.94  12.45  12.59
  6.71   6.55   6.24   5.79   5.18   4.43   3.55   2.59   1.49   0.20
 -1.34  -3.19  -5.38  -7.00  -8.11  -5.82  -3.21  -0.66   1.45   2.88
  3.73   4.46   5.25   5.95   6.49   6.82   6.90   6.79   6.63   6.56
  6.46   6.34   6.23   6.12   6.04   5.97   5.91   5.81   5.68   5.54
  5.39   5.23   5.09   4.95   4.85   4.79   4.58   3.97   2.79   2.64
  2.26   2.68   3.65   4.08   4.19   3.99   3.36   3.71   3.77   3.47
  4.55   5.52   6.34   6.97   7.38   8.17   9.51  10.61  11.46  12.07
 12.59  13.05  13.24
  7.57   7.40   7.08   6.62   6.01   5.23   4.43   3.53   2.58   1.53
  0.36  -0.95  -2.31  -3.19  -3.26  -2.22  -0.81   0.76   2.24   3.40
  4.31   5.08   5.85   6.54   7.07   7.36   7.41   7.20   6.83   6.73
  6.60   6.41   6.27   6.15   6.07   6.05   6.03   5.95   5.85   5.72
  5.59   5.46   5.35   5.25   5.19   5.16   5.11   4.86   4.44   4.29
  4.19   4.35   4.70   4.94   5.02   4.86   4.33   4.70   4.65   4.15
  4.98   6.08   6.97   7.60   8.32   9.46  10.54  11.46  12.21  12.80
 13.36  13.76  13.94
  8.48   8.28   7.96   7.50   6.89   6.10   5.29   4.49   3.66   2.83
  2.01   1.08   0.12  -0.60  -0.57  -0.08   0.77   1.93   3.10   4.17
  4.97   5.66   6.44   7.12   7.64   7.98   8.12   7.98   7.64   7.48
  7.34   7.16   6.98   6.80   6.56   6.30   6.22   6.13   6.02   5.90
  5.78   5.68   5.59   5.52   5.49   5.51   5.81   5.92   5.83   5.75
  5.69   5.69   5.75   5.88   6.01   6.03   5.92   5.94   5.82   5.51
  5.25   6.73   7.72   8.60   9.60  10.56  11.45  12.24  12.90  13.43
 13.90  14.23  14.40
  9.47   9.17   8.84   8.41   7.81   6.99   6.14   5.34   4.60   3.97
  3.42   2.82   2.15   1.52   1.52   1.88   2.64   3.63   4.63   5.61
  6.64   7.34   7.98   8.52   8.96   9.23   9.32   9.20   8.95   8.73
  8.54   8.35   8.12   7.87   7.56   7.12   6.91   6.76   6.62   6.50
  6.40   6.33   6.29   6.29   6.34   6.48   6.89   7.10   7.15   7.13
  7.05   6.90   6.69   6.75   7.07   7.25   7.29   7.27   7.12   6.75
  6.06   7.73   8.74   9.75  10.65  11.48  12.24  12.93  13.52  13.99
 14.39  14.69  14.83
 10.17   9.98   9.72   9.37   8.83   7.81   6.84   6.02   5.39   4.91
  4.61   4.33   4.04   3.69   3.78   4.38   5.19   6.11   7.06   8.06
  9.04   9.55   9.97  10.33  10.58  10.69  10.66  10.51  10.25   9.94
  9.65   9.39   9.12   8.82   8.51   8.19   7.93   7.72   7.55   7.41
  7.33   7.30   7.34   7.43   7.58   7.79   8.09   8.31   8.42   8.44
  8.35   8.06   7.27   7.31   8.16   8.48   8.60   8.60   8.49   8.18
  7.44   9.06  10.04  10.89  11.66  12.37  13.02  13.62  14.13  14.56
 14.91  15.17  15.30
 10.38  10.34  10.18   9.93   9.61   8.59   7.42   6.55   5.95   5.58
  5.41   5.35   5.35   5.44   5.85   6.65   7.50   8.40   9.29  10.12
 10.69  11.20  11.49  11.75  11.88  11.90  11.81  11.64  11.38  11.05
 10.67  10.31   9.99   9.66   9.35   9.04   8.76   8.51   8.30   8.15
  8.07   8.09   8.20   8.37   8.59   8.86   9.18   9.44   9.58   9.65
  9.63   9.51   9.29   9.31   9.57   9.72   9.81   9.85   9.83   9.80
  9.85  10.55  11.25  11.93  12.57  13.17  13.73  14.25  14.71  15.09
 15.41  15.64  15.75
 10.59  10.52  10.37  10.14   9.76   8.86   7.68   6.76   6.23   6.04
  5.95   6.02   6.22   6.59   7.27   8.07   8.98   9.91  10.81  11.59
 12.17  12.60  12.86  13.03  13.10  13.06  12.95  12.77  12.49  12.15
 11.71  11.25  10.81  10.46  10.13   9.84   9.52   9.22   8.97   8.77
  8.67   8.73   8.96   9.21   9.50   9.83  10.14  10.38  10.54  10.63
 10.65  10.62  10.57  10.58  10.66  10.71  10.77  10.85  10.93  11.06
 11.28  11.72  12.25  12.80  13.35  13.88  14.39  14.85  15.25  15.60
 15.88  16.08  16.17
 10.82  10.75  10.61  10.43   9.86   8.78   7.65   6.49   6.10   6.29
  6.42   6.64   6.98   7.48   8.18   9.00  10.00  11.03  12.00  12.83
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
  13.48   13.88   14.15   14.24   14.24   14.18   14.06   13.89   13.64   13.31
  12.82   12.30   11.78   11.36   11.05   10.82   10.66   10.48   10.30   10.14
  10.06    9.94    9.86   10.02   10.41   10.71   10.95   11.13   11.27   11.36
  11.38   11.38   11.37   11.38   11.42   11.48   11.55   11.67   11.83   12.01
  12.27   12.63   13.08   13.56   14.05   14.54   15.00   15.41   15.78   16.09
  16.34   16.51   16.60
  11.06   10.99   10.86   10.68   10.03    8.76    7.64    6.52    6.20    6.48
   6.73    7.06    7.49    8.06    8.79    9.80   10.94   12.04   13.04   13.92
  14.62   15.02   15.23   15.29   15.25   15.19   15.10   14.99   14.80   14.58
  14.33   13.92   13.16   12.74   12.48   12.33   12.33   12.37   12.42   12.45
  12.34   11.98   11.54   11.40   11.50   11.63   11.75   11.86   11.96   12.04
  12.05   12.04   12.03   12.04   12.07   12.15   12.28   12.42   12.61   12.84
  13.12   13.46   13.87   14.30   14.74   15.18   15.59   15.97   16.32   16.61
  16.84   16.99   17.07
  11.28   11.22   11.08   10.89   10.28    8.60    7.56    6.77    6.42    6.61
   6.87    7.27    7.76    8.35    9.17   10.30   11.55   12.75   13.87   14.86
  15.59   16.03   16.22   16.28   16.26   16.22   16.15   16.11   16.07   16.03
  16.09   16.07   15.66   15.49   15.45   15.43   15.43   15.40   15.42   15.35
  15.08   14.59   13.84   13.18   12.63   12.64   12.68   12.72   12.73   12.71
  12.69   12.66   12.63   12.63   12.65   12.74   12.90   13.09   13.33   13.60
  13.90   14.24   14.61   15.00   15.40   15.80   16.21   16.58   16.92   17.20
  17.42   17.56   17.63
  11.50   11.43   11.27   11.03   10.72    9.81    8.80    7.71    6.80    6.61
   6.78    7.34    7.79    8.27    9.00   10.15   11.73   13.29   14.67   15.78
  16.55   17.01   17.26   17.38   17.39   17.32   17.27   17.28   17.36   17.47
  17.64   17.81   18.43   19.00   19.36   19.54   19.59   19.51   19.32   18.79
  18.35   17.62   16.52   15.33   14.17   13.65   13.68   13.64   13.56   13.43
  13.34   13.28   13.24   13.24   13.28   13.39   13.57   13.80   14.08   14.44
  14.73   15.06   15.40   15.75   16.11   16.48   16.87   17.24   17.58   17.88
  18.08   18.21   18.26
  11.73   11.64   11.45   11.16   10.74   10.15    9.51    8.36    7.22    6.85
   6.92    7.43    7.70    7.86    8.34    9.39   11.61   13.73   15.46   16.72
  17.57   18.07   18.37   18.51   18.56   18.53   18.55   18.62   18.76   19.04
  19.41   19.90   21.26   22.35   23.07   23.40   23.50   23.65   23.45   22.69
  21.82   20.71   19.41   17.84   16.32   15.19   14.74   14.58   14.42   14.25
  14.10   13.98   13.90   13.89   13.94   14.06   14.27   14.56   14.94   15.44
  15.75   16.05   16.35   16.66   16.98   17.31   17.67   18.02   18.37   18.76
  18.93   19.09   19.06
  11.98   11.88   11.67   11.34   10.86   10.22    9.38    8.19    6.94    7.16
   7.24    7.62    7.59    7.06    7.12    7.33   11.26   14.25   16.42   17.93
  18.96   19.39   19.57   19.66   19.73   19.80   19.92   20.10   20.36   20.83
  21.49   22.43   23.82   25.14   26.16   26.96   27.59   27.91   27.76   27.11
  25.75   24.20   22.59   20.79   18.83   17.16   15.99   15.65   15.36   15.14
  14.97   14.87   14.80   14.82   14.88   15.02   15.27   15.60   16.11   16.76
  17.11   17.42   17.62   17.85   18.10   18.37   18.68   19.00   19.33   19.65
  19.93   20.27   20.14
  12.26   12.15   11.93   11.58   11.08   10.42    9.51    8.14    7.51    8.07
   8.04    8.08    7.94    7.76    7.67    7.43   11.54   15.38   17.90   19.75
  20.98   20.93   20.81   20.76   20.78   20.91   21.12   21.46   21.94   22.49
  23.39   24.73   26.84   28.74   30.12   31.31   32.19   32.37   32.18   31.48
  29.91   28.07   25.98   23.82   21.56   19.47   17.86   17.02   16.61   16.31
  16.10   16.00   15.99   16.06   16.17   16.42   16.83   17.28   18.00   18.94
  19.52   19.85   19.72   19.77   19.91   20.11   20.36   20.62   20.90   21.19
  21.50   21.97   21.83
  12.59   12.48   12.24   11.89   11.40   10.78   10.04    9.25    8.83    8.92
   9.15    9.11    8.90    8.91    8.50    7.65   11.76   17.57   20.10   22.41
  24.68   22.86   22.15   21.86   21.76   21.94   22.31   22.93   23.79   25.34
  26.94   28.85   31.39   33.40   34.95   36.13   36.92   37.31   37.12   36.39
  34.54   32.47   30.04   27.44   24.48   21.76   20.01   18.79   18.31   17.93
  17.62   17.39   17.38   17.46   17.62   18.12   18.83   19.96   21.12   22.22
  23.13   23.81   23.31   23.12   23.10   23.18   23.32   23.50   23.69   23.90
  24.14   24.61   24.85
  13.07   12.95   12.71   12.35   11.87   11.29   10.66   10.08    9.74    9.72
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
   9.82    9.89   10.03    9.90    9.47    8.13    9.19   15.49   19.79   23.01
  25.90   24.68   24.05   24.12   25.04   25.86   26.70   27.72   29.22   31.38
  33.28   35.30   37.60   39.65   41.29   42.50   43.26   43.67   43.27   42.23
  40.19   37.76   34.95   31.81   28.55   25.40   23.02   21.21   20.41   19.95
  19.55   19.38   19.36   19.55   20.14   21.13   22.21   23.89   25.45   26.95
  28.39   28.73   27.85   27.45   27.25   27.21   27.23   27.28   27.35   27.40
  27.42   27.45   27.50
  13.97   13.86   13.62   13.27   12.78   12.24   11.68   11.22   10.99   11.11
  11.33   11.48   11.51   11.41   11.17   10.90   10.61   13.86   20.40   24.05
  26.93   26.71   27.37   28.80   30.73   32.22   33.59   35.02   36.70   38.62
  40.58   42.88   45.39   47.67   49.50   50.75   51.36   51.32   50.48   48.86
  46.49   43.56   40.19   36.55   32.79   29.46   26.89   24.84   23.62   22.90
  22.07   21.83   21.81   22.14   23.30   24.77   26.35   28.32   30.32   32.47
  33.47   33.45   32.51   32.14   31.81   31.67   31.59   31.51   31.43   31.32
  31.12   30.86   30.72
  15.64   15.63   15.63   15.47   15.20   14.68   14.03   13.34   12.92   13.02
  13.56   13.64   13.61   13.64   13.74   14.22   16.04   19.64   23.81   25.79
  27.50   29.43   31.74   33.99   36.15   38.06   39.84   41.62   43.40   45.38
  47.37   50.31   53.39   56.18   58.36   59.72   60.18   59.77   58.41   56.04
  53.09   49.46   45.49   41.49   37.41   33.54   30.69   28.81   27.60   26.88
  26.51   25.91   25.62   25.89   27.05   28.68   31.09   33.66   36.14   37.27
  37.61   37.83   37.69   37.87   38.17   38.11   37.89   37.64   37.36   37.00
  36.43   35.93   35.70
  29.11   29.06   28.97   28.58   27.92   26.53   24.90   22.93   20.65   18.42
  16.45   16.22   16.48   16.88   17.67   19.09   21.44   24.56   28.86   28.50
  28.04   32.16   35.45   38.28   40.82   43.06   45.13   47.24   49.31   51.70
  54.57   58.74   62.94   66.83   69.76   71.37   71.59   70.79   68.77   64.83
  61.02   56.59   51.44   46.60   42.20   38.10   35.61   34.98   34.80   34.13
  33.34   31.65   30.59   30.39   31.11   32.94   35.98   39.25   40.78   43.39
  45.19   46.49   46.84   46.35   47.40   47.13   46.55   45.97   45.42   44.86
  44.22   43.47   43.16
  55.34   55.02   54.31   53.04   51.07   48.18   44.21   39.77   33.89   28.03
  24.26   23.17   23.08   23.34   24.09   25.21   26.42   27.79   29.50   29.80
  31.38   35.39   39.04   42.22   44.94   47.36   49.58   52.08   55.12   58.57
  64.77   71.54   78.29   85.17   90.06   92.21   91.47   90.24   88.05   91.92
  88.78   84.83   80.10   74.18   64.93   54.17   47.04   46.15   46.92   44.47
  41.32   36.80   34.63   33.84   34.28   36.18   40.19   42.82   47.47   53.87
  65.02   70.14   72.11   69.02   63.27   61.06   59.43   58.18   57.21   56.39
  55.66   55.04   54.72
  85.32   84.65   83.19   80.73   76.99   71.95   65.46   58.35   48.65   37.66
  34.56   32.47   31.39   30.82   30.73   30.80   30.61   30.00   30.25   30.70
  33.54   38.66   42.96   46.60   49.59   52.43   55.90   59.61   63.86   69.01
  76.71   84.95   94.97  110.84  119.48  122.62  117.72  116.37  126.30  158.95
 204.75  236.09  243.62  244.19  250.34  157.82  162.49  135.16  115.61   96.76
  80.57   81.14   75.61   66.28   53.64   45.82   44.24   73.59   79.81   88.61
 100.32  103.41  102.93   98.45   89.37   83.82   80.25   77.82   76.10   74.84
  73.90   73.24   72.90
 108.28  107.30  105.16  101.53   95.71   88.24   80.17   71.85   62.32   50.28
  42.56   39.54   37.69   36.62   35.85   35.00   33.54   31.39   30.52   31.23
  35.07   41.70   46.88   50.82   54.34   57.83   61.92   66.27   70.99   76.85
  84.44   93.94  105.04  117.85  127.18  133.95  138.77  142.94  154.30  177.13
 224.80    0.00    0.00    0.00    0.00    0.00  259.18  241.20  193.18  159.25
 142.59  137.79  123.06   96.49   50.01   49.30   91.67  117.84  126.79  133.35
 135.78  132.72  123.81  118.51  111.65  105.11   99.69   96.07   93.59   91.86
  90.67   89.91   89.54
 118.54  117.40  114.94  110.85  104.66   96.01   86.01   76.04   67.61   58.16
  49.38   44.74   42.14   40.65   39.44   37.96   35.48   32.18   31.01   31.51
  36.55   44.08   49.08   53.11   56.81   60.20   65.14   70.27   78.99   87.55
  96.18  106.12  117.31  126.73  135.73  147.01  166.56  162.18  166.96  185.45
 234.44    0.00    0.00    0.00    0.00    0.00  298.83  290.22  242.30  198.40
 183.45  167.87  145.85  110.11   51.48   85.35  118.78  142.81  155.30  159.80
 155.63  149.88  138.47  128.44  121.94  115.60  109.60  105.44  102.58  100.61
  99.28   98.45   98.05
```

```
         1         1         1

BLOCK CENTER FLOW INPUT PACKAGE:

         1        -6  1.00E+30         0  5.00E-01         1         0
 0
         0        1.
         0     1000.
         0     1000.
        11 1.157e-05(12F7.0)                -11
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  /*  01
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.
   200.   200.   200.   200.     0.     0.     0.     0.     0.     0.     0.     0.  /*  02
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.
   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.   400.
   500.   500.   500.   500.   500.   500.   500.   500.   500.   500.   500.   500.
   500.
   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.     0.  /*  03
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.   300.
   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.   300.
   300.   300.   300.   300.   300.   500.   500.   300.   300.   300.   400.   500.
   600.   600.   600.   600.   600.   600.   600.   600.   600.   600.   600.   600.
   600.
   500.   400.   400.   400.   400.   400.   400.   400.   400.   400.   900.   900.  /*  04
   900.   900.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.   400.
   400.   400.   400.   500.   400.   400.   500.   500.   500.   500.   500.   500.
   500.   500.   500.   500.   500.   500.   500.   500.   500.   400.   500.   600.
   700.   700.   700.   700.   700.   700.   700.   700.   700.   700.   700.   700.
   700.
   750.   500.   500.   500.   500.   500.   500.   500.   500.   500.  1000.  1000.  /*  05
  1000.  1000.  1000.  1000.  1000.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.   750.   750.
   750.   750.   750.   750.   500.   500.  1000.  1000.  1000.  1000.  1000.  1000.
  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.   800.   800.   800.
   800.   800.   800.   800.   800.   800.   800.   800.   800.   800.   800.   800.
   800.
   800.   750.   750.   600.   600.   600.   600.   600.   600.   600.  1100.  1100.  /*  06
  1100.  1100.  1100.  1100.  1100.  1100.   800.   600.   600.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.  5000.  5000.   600.
   600.   600.   600.  1000.  2000.  2500.  3000.  3000.  3500.  3600.  4000.  4800.
  6000.  6000.  4000.  4000.  2200.  2200.  2000.  1800.  1500.  1200.  1000.   900.
   900.   900.   900.   900.   900.   900.   900.   900.   900.   900.   900.   900.
   900.
  1000.  1000.  1000.  1000.  1000.   750.   750.  1000.  1000.  1000.  1200.  1200.  /*  07
  1200.  1200.  1200.  1200.  1200.  1200.   900.   700.   700.   700.  1000.  2000.
  3000.  4000.  5000.  5000.  5000.  5000.  5000.  5000.  6000.  6000.  6000.  1000.
  1000.  1500.  2000.  3200.  3200.  4000.  3600.  4000.  4000.  4400.  5000.  6000.
  7200.  7200.  6000.  5800.  4000.  4000.  3400.  2200.  2000.  1800.  1500.  1500.
  1200.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.
  1000.
  1250.  1250.  1250.  1250.  1250.  1250.  1250.  1250.  1250.  1250.  1500.  1500.  /*  08
  1500.  1500.  1500.  1500.  1500.  1500.  1000.  1000.  1000.  1000.  1000.  1000.
  2000.  3000.  4000.  6000.  6000.  6000.  6000.  6000.  7000.  7000.  6000.  5000.
  4000.  2500.  3000.  4400.  4400.  5000.  4400.  4600.  4600.  5200.  6000.  7500.
```

```
 8400.  8400.  7500.  6200.  6000.  5800.  4800.  4000.  3400.  2200.  2000.  2000.
 1800.  1500.  1500.  1250.  1250.  1250.  1250.  1250.  1250.  1250.  1250.  1250.
 1250.
 1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.  2000.  2000.  /*  09
 2000.  2000.  2000.  2000.  2000.  2000.  1500.  1500.  1500.  1500.  1500.  1500.
 2000.  3000.  5000.  5000.  7000.  7000.  7000.  7000.  8000.  8000.  8000.  9000.
 7000.  6000.  4500.  5600.  5600.  6000.  5200.  5300.  5300.  6500.  7800.  9000.
 9600.  9600.  9000.  7900.  7800.  7000.  6500.  5100.  4800.  4000.  3400.  3400.
 2600.  2450.  2450.  1700.  1700.  1500.  1500.  1300.  1300.  1300.  1100.  1100.
 1100.
 1750.  1750.  1750.  1750.  1750.  1750.  1750.  1750.  1750.  1750.  2000.  2500.  /*  10
 2750.  3000.  3000.  3000.  3000.  3000.  2500.  1750.  1750.  1750.  1750.  2500.
 9000.  9000.  9000.  9000.  9000.  9000.  9000.  9000. 10000. 15000. 15000. 20000.
25000. 25000. 25000. 30000. 30000. 30000. 30000.  6000.  6000.  7800.  9600. 10500.
10800. 10800. 10500.  9600.  9600.  8200.  8200.  6200.  6000.  5800.  4800.  4800.
 3400.  3400.  3400.  3000.  3000.  3000.  2000.  1800.  1800.  1800.  1500.  1500.
 1500.
 2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  /*  11
 3000.  3000.  7500. 10000. 10000. 10000.  5000.  5000.  5000.  5000.  5000.  5000.
10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000.
10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000.  9600. 11400. 12000.
12000. 12000. 12000. 11400. 11400. 10400. 10400.  9000.  9000.  6000.  6000.  5800.
 4800.  4800.  4800.  4500.  4000.  4000.  3400.  2200.  2200.  2200.  2000.  2000.
 2000.
 2250.  2250.  2250.  2250.  2250.  2250.  2250.  2250.  2250.  2250.  2250.  2250.  /*  12
 2250.  8000.  9000. 10000. 12500. 14000. 14000. 18000. 18000. 15000. 10000. 10000.
10000. 12500. 12500. 12500. 12500. 12500. 12500. 12500. 12500. 12500. 12500. 12500.
12500. 12500. 12500. 12500. 12500. 12500. 12500. 12500. 12500. 12500. 13200. 13400.
13400. 13400. 13400. 13000. 13000. 12600. 12600. 12000. 12000. 10000. 10000.  6200.
 6000.  6000.  6000.  5800.  5800.  5800.  5000.  5000.  5000.  5000.  5000.  5000.
 5000.
 2500.  2500.  2500.  2500.  2500.  2500.  2500.  2500.  2500.  2500.  2500.  2500.  /*  13
 2500.  8000. 10000. 12500. 14000. 14000. 18000. 30000. 60000. 40000. 20000. 15000.
12500. 15000. 15000. 15000. 15000. 15000. 15000. 15000. 15000. 15000. 15000. 15000.
15000. 15000. 15000. 15000. 15000. 15000. 15000. 15000. 15000. 15000. 14800. 14800.
14800. 14800. 14800. 14800. 14800. 14800. 14800. 14800. 14800. 14800. 14800. 14800.
14800. 14800. 14800. 13000. 12000. 10000. 10000. 10000. 10000. 10000. 10000. 10000.
10000.
 2750.  2750.  2750.  2750.  2750.  2750.  2750.  2750.  2750.  2750.  2750.  2750.  /*  14
 8750. 10000. 14000. 14000. 14000. 14000. 18000. 30000. 40000. 25000. 20000. 20000.
15000. 20000. 25000. 25000. 22500. 22500. 25000. 25000. 25000. 25000. 25000. 25000.
25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000.
25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 22000. 22000. 22000. 22000.
22000. 22000. 20000. 20000. 20000. 20000. 17500. 17000. 17000. 17000. 14000. 12500.
12500.
 3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  /*  15
 8800. 15000. 15000. 15000. 15000. 20000. 25000. 35000. 40000. 40000. 30000. 30000.
30000. 30000. 30000. 30000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000.
28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000.
28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000. 28000.
20000. 20000. 20000. 20000. 20000. 20000. 20000. 20000. 20000. 20000. 15000. 15000.
15000.
 3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  /*  16
 8500. 12500. 12500. 13000. 13000. 12500. 15000. 15000. 40000. 40000. 35000. 35000.
35000. 35000. 30000. 30000. 30000. 30000. 30000. 30000. 30000. 30000. 30000. 30000.
30000. 30000. 30000. 30000. 30000. 30000. 30000. 30000. 30000. 30000. 30000. 30000.
30000. 30000. 30000. 30000. 30000. 30000. 30000. 28000. 25000. 22500. 22500. 22500.
22500. 22500. 22500. 22500. 22500. 22500. 22500. 22500. 22500. 22500. 25000. 25000.
25000.
 4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  /*  17
 8500. 10000. 10000. 10000.  9000.  7500.  7500.  7500.  5000.  7500. 10000. 11000.
12500. 15000. 20000. 20000. 25000. 30000. 35000. 35000. 35000. 35000. 35000. 35000.
35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 30000. 30000.
```

```
 30000. 30000. 30000. 30000. 30000. 30000. 30000. 27500. 25000. 25000. 25000. 25000.
 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000. 25000.
 25000.
 25000.  4500.  4500.  4500.  4500.  4500.  4500.  4500.  4500.  4500.  4500.  4500.  /*  18
  5000. 10000. 10000.  8000.  8000.  8500.  8500.  8000. 10000. 10000. 13400. 15000.
 20000. 25000. 30000. 30000. 30000. 30000. 35000. 40000. 40000. 40000. 40000. 40000.
 40000. 40000. 40000. 40000. 40000. 40000. 40000. 40000. 40000. 40000. 35000. 35000.
 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000.
 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 35000. 30000. 30000.
 30000.
 30996. 30840. 30950. 30988. 31250.  5000.  5000.  5000.  5000.  5000.  6000.  5000.  /*  19
  5000. 10000. 10000.  9000.  9000.  9000.  9000.  9000. 10000. 12500. 15000. 17500.
 20000. 25000. 30000. 30000. 35000. 35000. 40000. 45000. 45000. 45000. 45000. 45000.
 45000. 45000. 45000. 45000. 45000. 45000. 45000. 45000. 45000. 45000. 40000. 40000.
 40000. 40000. 40000. 40000. 40000. 40000. 40000. 40000. 40000. 40000. 40000. 40000.
 40000. 35000. 25000. 25000. 30000. 35000. 40000. 40000. 40000. 40000. 35000. 35000.
 35000.
 32246. 31990. 32082. 32162. 32382.  5200.  5200.  5200.  5200.  5200.  6000.  6000.  /*  20
  6500. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 15000. 15000. 20000.
 25000. 30000. 33750. 33750. 33750. 33750. 33750. 35000. 42000. 42000. 42000. 42000.
 42000. 42000. 42000. 42000. 42000. 42000. 42000. 42000. 42000. 45000. 45000. 45000.
 45000. 50000. 60000. 60000. 70000. 35000. 40000. 35000. 35000. 35000. 35000. 35000.
 40000. 35000. 25000. 25000. 30000. 35000. 45000. 45000. 45000. 45000. 45000. 45000.
 45000.
 33750. 33516. 33462. 33440.  5500.  5500.  5500.  5500.  5500.  5500.  5500.  5500.  /*  21
  6000.  6500. 12500. 12500. 12500. 12500. 12500. 12500. 12500. 15000. 17500. 20000.
 25000. 30000. 35000. 35000. 35000. 35000. 35000. 35000. 30000. 30000. 30000. 30000.
 20000. 15000. 12500. 10000.  8000. 10000. 20000. 25000. 30000. 40000. 50000. 60000.
 65000. 70000. 70000. 70000. 70000. 70000. 60000. 50000. 45000. 40000. 40000. 35000.
 30000. 25000. 20000. 20000. 20000. 20000. 40000. 50000. 50000. 50000. 50000. 50000.
 50000.
 41012. 35060. 34928. 34882.  6000.  6000.  6000.  6000.  6000.  6000.  6000.  6000.  /*  22
  6000.  6500.  6500.  7500. 10000. 12500. 15000. 15000. 17500. 20000. 25000. 30000.
 35000. 40000. 41000. 39000. 36000. 35000. 20000. 15000. 15000. 15000. 15000. 15000.
 15000. 12500. 10000.  7500.  7500.  8000.  9000. 10000. 30000. 35000. 40000. 45000.
 50000. 55000. 60000. 60000. 60000. 60000. 50000. 40000. 39000. 38000. 36000. 35000.
 25000. 25000. 20000. 15000. 15000. 15000. 25000. 35000. 45000. 45000. 45000. 45000.
 45000.
 41474. 39588. 36704. 36582.  6200.  6200.  6200.  6200.  6200.  6200.  6200.  6200.  /*  23
  6200.  7500.  7500. 10000. 15000. 17500. 18000. 20000. 22500. 23000. 24000. 25000.
 25000. 30000. 35000. 35000. 30000. 25000. 22500. 20000.  6000.  6000.  6000.  6000.
  6000.  6000.  6000.  6000.  6000.  6000.  8000. 10000. 15000. 25000. 30000. 40000.
 45000. 50000. 50000. 50000. 45000. 40000. 38000. 36000. 34000. 32000. 30000. 29000.
 25000. 25000. 25000. 25000. 20000. 20000. 20000. 20000. 20000. 20000. 20000. 20000.
 20000.
 41828. 40752. 38346. 38134. 37938.  6500.  6500.  6500.  6500.  6500.  6500.  6500.  /*  24
  6500.  7500.  9000. 10000. 12500. 15000. 17500. 20000. 25000. 30000. 25000. 25000.
 25000. 32000. 32000. 32000. 32000. 28000. 26000. 25000.  6000.  6000.  6000.  6000.
  6000.  5000.  5000.  5000.  5000.  6000.  6000.  7500. 10000. 15000. 25000. 35000.
 40000. 45000. 45000. 45000. 45000. 42000. 40000. 38000. 36000. 35000. 30000. 29000.
 27000. 25000. 22500. 20000. 15000. 15000. 15000. 15000. 15000. 15000. 15000. 15000.
 15000.
 40662. 40938. 39814. 39512. 39222. 38920. 38750.  7000.  7000.  7000.  7000.  7000.  /*  25
  9000. 11000. 12500. 13000. 15000. 17000. 20000. 25216. 24770. 24292. 24362. 23750.
 23000. 22000. 22000. 22000. 22000. 18000. 16000. 12500.  6000.  6000.  6000.  6000.
  6000.  5000.  5000.  3500.  5000.  6000.  6000.  7000.  7500. 10000. 20000. 30000.
 35000. 40000. 45000. 45000. 45000. 42000. 40000. 40000. 38000. 32000. 30000. 25000.
 25000. 20000. 15000. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000. 10000.
 10000.
 42234. 41674. 41272. 40860. 40462. 40050. 39746. 39448. 39148.  7000.  7000.  7000.  /*  26
  7000. 10000. 12500. 13000. 14000. 15000. 17000. 20000. 22000. 23000. 24000. 24000.
 24200. 22000. 22000. 20000. 18000. 17000. 15000. 10000. 10000.  9000.  9000.  6500.
  4500.  4500.  4500.  3000.  4000.  4500.  5000.  5000.  5000.  7500. 10000. 25000.
```

```
 30000. 35000. 40000. 42000. 35000. 30000. 27000. 25000. 15000. 15000. 15000. 15000.
 15000. 15000. 15000. 15000. 10000.  9000.  9000.  9000.  9000.  9000.  9000.  9000.
  9000.
 42956. 42398. 41926. 41432. 40946. 40446. 40028. 39622. 39226. 38778.  7000.  7000.  /*  27
  7000.  9000. 12000. 12000. 12000. 14000. 15000. 15876. 20000. 22000. 23000. 24000.
 24000. 22000. 22000. 20000. 15000. 15000. 15000. 10000.  4000.  4000.  4000.  4000.
  4000.  4000.  4000.  3000.  4000.  4000.  4500.  5000.  5000.  8000. 10000. 25000.
 25000. 25000. 25000. 25000. 20000. 20000. 15000. 12500. 10000. 10000. 10000. 10000.
  7500.  7500.  7500.  7500.  7500.  7500.  7500.  7500.  7500.  7500.  7500.  7500.
  7500.
 42320. 41702. 41110. 40482. 39866. 39240. 38656. 38088. 37524. 36918. 36294. 35654.  /*  28
  7500.  7500.  7500. 10000. 11000. 12000. 13000. 13000. 15000. 15000. 16000. 18000.
 19000. 18000. 15000. 12500. 10000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.
  4000.  3000.  3000.  2500.  3000.  3000.  3000.  3000.  4000.  9000. 11000. 15000.
 15000. 15000. 15000. 15000. 15000. 15000. 15000. 10000. 10000.  5000.  5000.  5000.
  5000.  5000.  5000.  5000.  5000.  5000.  5000.  5000.  5000.  5000.  5000.  5000.
  5000.
 27000. 27000. 27000. 27000. 27000. 27000. 27000. 26800. 26400. 26000. 26000. 26000.  /*  29
 26000. 25600. 23600. 10000.  7000.  7000.  7000.  7000.  7000.  7000.  6000.  5000.
  2200.  2200.  2200.  2300.  2300.  2300.  2300.  2200.  2200.  2200.  2200.  2200.
  2200.  2200.  2200.  2200.  2200.  2200.  2200.  3000.  3500.  4000.  5000.  7500.
 10000. 10000. 10000.  7500.  7500.  7500.  4500.  3500.  3500.  3500.  3500.  3500.
  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.  3500.
  3500.
 13970. 13364. 12790. 12268. 11732. 11224. 10660. 10060.  9428.  8892.  8122.  7890.  /*  30
  7452.  7060.  6988.  6000.  6000.  6000.  6000.  6000.  6000.  5000.  2000.  1800.
  1800.  1800.  1800.  1800.  2000.  2000.  2000.  1800.  1800.  1800.  1800.  1800.
  1800.  1800.  1800.  1800.  1800.  1800.  2200.  2500.  3000.  3500.  4000.  5000.
  6000.  7500.  7500.  7000.  7000.  7000.  4000.  3500.  3000.  3000.  3000.  3000.
  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.
  3000.
  6828.  6314.  4828.  4398.  3350.  3246.  3110.  3678.  4274.  6974.  6922.  8262.  /*  31
  7026.  6482.  5400.  4952.  3150.  5000.  6000.  6000.  2000.  2000.  1800.  1800.
  1800.  1800.  1800.  1800.  1900.  1900.  1800.  1600.  1600.  1600.  1600.  1600.
  1600.  1600.  1600.  1600.  1600.  1800.  2000.  2500.  2500.  3000.  4000.  5000.
  6000.  7000.  3000.  3000.  3000.  3000.  3000.  3000.  2000.  2000.  2000.  2000.
  2000.  2000.  2000.  1800.  1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.
  1500.
   500.   500.   500.   500.   500.   500.   500.   500.   500.   986.  5400.  4952.  /*  32
  3150.  2700.  2000.  1500.  2000.  4000.  6000.  6000.  1700.  1700.  1600.  1600.
  1600.  1600.  1600.  1600.  1600.  1600.  1000.  1000.  1000.  1000.  1000.  1000.
  1000.  1000.  1000.  1000.  1100.  1100.  1500.  2000.  2000.  2000.  2000.  2000.
  2000.  2200.  2200.  2200.  2200.  2200.  2200.  2000.  2000.  2000.  1000.  1000.
   700.   700.   700.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.
  1000.
   300.   300.   300.   300.   300.   300.   300.   300.   300.   866.  1000.  1000.  /*  33
  1000.  1000.  1000.  1000.  1000.  2000.  6000.  6000.  1300.  1300.  1400.  1400.
  1600.  1600.  1600.  1600.  1200.  1200.   500.   500.   500.   500.   500.   500.
   500.   500.   500.   200.   200.   200.   200.   200.   200.   200.   400.  1000.
  1500.  2200.  2200.  2200.  2200.  2200.  1800.  1800.  1600.  1600.  1000.   500.
   200.   200.   200.   200.   500.   500.   500.   500.   500.   500.   500.   500.
   500.
   200.   200.   200.   200.   200.   200.   200.   200.   200.   700.   700.   800.  /*  34
   800.   800.   800.   800.   800.  2000.  6000.  6000.   800.   800.   800.   800.
   800.   800.   500.   500.   500.   500.   500.   500.   500.   400.   400.   400.
   400.   400.   150.   100.    40.    30.    30.    30.    20.    20.    20.    70.
   200.   200.   200.    50.    50.    50.    50.    50.    50.    50.   100.   100.
   150.   150.   230.   230.   230.   230.   230.   230.   230.   230.   230.   230.
   230.
   200.   200.   200.   200.   200.   200.   200.   200.   200.   200.   700.   700.  /*  35
   700.   600.   600.   600.   600.  1000.  6000.  6000.   700.   600.   600.   700.
   600.   600.   600.   600.   600.   600.   500.   400.   400.   400.   400.   400.
   400.   200.   250.    70.    20.    20.    20.    20.    20.    20.   200.   200.
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
   200.   200.    50.    50.    50.    50.    50.    50.    50.    50.    50.    50.
   100.   100.   230.   230.   230.   230.   230.   230.   230.   230.   230.   230.
   230.
   200.   200.   200.   200.   200.   200.   200.   400.   400.   400.   400.   400.  /*  36
   400.   400.   400.   400.   400.  1000.  6000.  6000.   400.   600.   700.   700.
   700.   700.   300.   300.   100.   100.   100.   100.   100.   200.   200.   200.
   200.   200.   300.   100.    20.    20.    20.    20.    20.    20.   100.   100.
   100.   100.    50.    50.    50.    50.    50.    50.    50.    50.    50.    50.
   100.   100.   100.   220.   220.   220.   220.   220.   220.   220.   220.   220.
   220.

RECHARGE INPUT PACKAGE:

        18 2.64e-09 (12F7.0)                 0
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0. /*  01
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  /*  02
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  /*  03
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  /*  04
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  /*  05
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  /*  06
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  /*  07
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.
```

```
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  /*  08
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  /*  09
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  /*  10
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  /*  11
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  /*  12
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  /*  13
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  /*  14
     0.      5.      5.      5.      5.      5.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  /*  15
     5.      5.      5.      5.      5.      5.      5.      5.      5.      5.      5.      5.
     3.      3.      3.      3.      3.      3.      3.      3.      3.      3.      3.      3.
     3.      3.      3.      3.      3.      3.      3.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      4.     10.  /*  16
    10.     10.     10.     10.     10.     10.     10.     10.     10.     10.     10.     10.
     4.      3.      3.      3.      3.      3.      3.      3.      3.      3.      3.      3.
     3.      3.      3.      3.      3.      3.      3.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
  0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    4.   10.  /*  17
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
  4.    3.    3.    3.    3.    3.    3.    3.    3.    3.    3.    3.
  3.    3.    3.    3.    3.    3.    3.    0.    0.    0.    0.    0.
  0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  0.
  2.    2.    2.    2.    2.    0.    0.    0.    0.    0.    4.   10.  /*  18
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
  4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
  4.    4.    4.    4.    4.    4.    4.    0.    0.    0.    0.    0.
  0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  0.
  2.    2.    2.    2.    2.    0.    0.    0.    0.    0.    4.   10.  /*  19
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
  4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
  4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
  4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
  4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
  4.
  4.    4.    4.    4.    2.    2.    2.    2.    2.    2.    4.    4.  /*  20
  4.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
 10.   10.   10.    4.    4.    8.    8.    8.    8.    8.    8.    8.
  8.
  4.    4.    4.    4.    2.    2.    2.    2.    2.    2.    2.    2.  /*  21
  2.    2.    2.   10.   10.   10.   10.   10.   10.   10.   10.   10.
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
 10.   10.   12.   12.   12.   12.   12.   12.   12.   12.   12.   10.
 10.   10.   10.    4.    4.    8.    8.    8.    8.    8.    8.    8.
  8.
  8.    8.    8.    3.    2.    2.    2.    2.    2.    2.    2.    2.  /*  22
  2.    2.    2.    2.    2.    4.   10.   10.   10.   10.   10.   10.
 10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
 10.   10.   12.   12.   12.   12.   12.   12.   12.   12.   12.   12.
 12.   15.   15.   15.   15.   15.   15.   15.   15.   12.   12.   12.
 10.   10.    4.    4.    4.    4.    8.    8.    8.    8.    8.    8.
  8.
  8.    8.    8.    8.    3.    2.    2.    2.    2.    2.    2.    2.  /*  23
  2.    2.    2.    2.    2.    4.   10.   12.   12.   12.   12.   12.
 12.   12.   12.   12.   12.   12.   12.   12.   12.   15.   15.   15.
 15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.
 15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   10.
 10.    8.    8.    8.    8.    8.    8.    8.    8.    8.    8.    8.
  8.
 10.   10.   10.   10.   10.    2.    2.    2.    2.    2.    2.    2.  /*  24
  2.    2.    2.    2.    2.    2.    3.   15.   15.   15.   15.   15.
 15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.
 15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.
 15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   12.   10.
 12.   15.   15.   15.   12.   10.   10.   10.   10.    8.    8.    8.
  8.
 12.   12.   12.   12.   10.   10.   10.    3.    3.    3.    3.    3.  /*  25
  3.    3.    3.    3.    3.    3.    4.    4.   10.   10.   10.   10.
 10.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.
 15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   15.
 15.   15.   15.   15.   15.   15.   15.   15.   15.   15.   12.   10.
 12.   15.   15.   12.   10.   10.   10.   10.   10.    8.    8.    8.
  8.
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
 12.    12.    12.    12.    12.    12.    10.    10.     4.     4.     4.     4.  /*  26
  4.     4.     4.     4.     4.     4.     4.     4.     8.     8.     8.     8.
 10.    15.    15.    18.    18.    18.    18.    18.    18.    18.    18.    18.
 18.    15.    15.    15.    15.    15.    15.    15.    15.    15.    15.    15.
 18.    18.    18.    18.    18.    18.    18.    18.    18.    15.    12.    10.
 12.    15.    15.    15.    15.    15.    15.    12.    10.     8.     8.     8.
  8.
 12.    12.    12.    12.    12.    12.    12.    10.    10.     4.     4.     4.  /*  27
  4.     4.     4.     4.     4.     4.     4.     4.     8.     8.    10.    10.
 10.    10.    10.    12.    15.    18.    18.    18.    18.    18.    18.    18.
 18.    15.    15.    15.    15.    15.    15.    15.    15.    15.    15.    15.
 18.    18.    18.    18.    18.    18.    18.    18.    18.    18.    12.    10.
 10.    12.    15.    15.    15.    15.    15.    15.    12.    10.     8.     4.
  4.
 12.    12.    12.    12.    12.    12.    12.    12.    12.    10.    10.     4.  /*  28
  4.     4.     4.     4.     4.     4.     4.     4.     4.     4.    10.    10.
 10.    10.    10.    12.    15.    18.    18.    18.    18.    18.    18.    18.
 18.    15.    15.    15.    15.    15.    15.    15.    15.    15.    15.    15.
 18.    18.    18.    18.    18.    18.    18.    18.    18.    18.    18.    15.
 10.    12.    15.    15.    15.    15.    15.    15.    12.    10.     8.     4.
  4.
 15.    15.    15.    15.    15.    15.    15.    15.    15.    15.    15.    15.  /*  29
 15.    15.    15.    15.     4.     4.     4.     4.     4.     4.    10.    12.
 12.    12.    12.    12.    12.    12.    12.    12.    12.    12.    12.    12.
 12.    12.    12.    12.    12.    12.    15.    15.    15.    15.    15.    15.
 18.    18.    18.    18.    18.    18.    18.    18.    18.    18.    18.    15.
 10.    12.    15.    15.    15.    15.    15.    15.    12.    10.     8.     4.
  4.
 12.    12.    12.    12.    12.    12.    12.    12.    12.    12.    12.    12.  /*  30
 12.    12.    12.    12.    12.     4.     4.     4.     4.     4.     4.    10.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.
 10.    12.    15.    15.    15.    15.    15.    15.    15.    15.    12.    10.
 10.    10.    12.    12.    12.    12.    12.    12.    12.    12.    10.     8.
  4.
 12.    12.    12.    12.    12.    12.    12.    12.    12.    12.    12.    12.  /*  31
 12.    12.    12.    12.    12.     4.     4.     4.     4.     8.     8.     8.
  8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
  8.     8.     8.     8.     8.     8.    10.    10.    10.    10.    10.    10.
 10.    10.    12.    12.    12.    12.    12.    12.    12.    12.    10.    10.
 12.    12.    12.    12.    12.    12.    12.    12.    12.    10.     8.     4.
  4.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.  /*  32
 10.    10.    10.    10.    10.     4.     4.     4.     4.     8.     8.     8.
  8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
  8.     8.     8.     8.     8.     8.    10.    10.    10.    10.    10.    10.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.
 12.    12.    12.    12.    12.    12.    12.    12.    12.    10.     8.     4.
  4.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.  /*  33
 10.    10.    10.    10.    10.     4.     4.     4.     4.     8.     8.     8.
  8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
  8.     8.     8.     8.     8.     8.    10.    10.    10.    10.    10.    10.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.
 10.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.  /*  34
 10.    10.    10.    10.    10.     4.     4.     4.     4.     8.     8.     8.
  8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
  8.     8.     8.     8.     8.     8.    10.    10.    10.    10.    10.    10.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.
 10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.    10.
 10.
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.  /*  35
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.  /*  36
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.     8.
     8.

WELL PACKAGE (INJECTION WELLS ALONG SOUTHERN MODEL BOUNDARY AND ESTIMATED WITHDRAWALS
FROM PUBLIC SUPPLY, INDUSTRIAL, AND IRRIGATION WELLS FOR MARCH 1995 HYDROLOGIC
CONDITIONS)

        70        -3
        70 /*                   Q (cfs)
         1        36        47      0.05  /*Injection well Quebrada Hicatea
         1        36        48      0.10  /*Injection well Quebrada Hicatea
         1        36        49      0.05  /*Injection well Quebrada Hicatea
         1        35        48      0.10  /*Injection well Quebrada Hicatea
         1        35        49      0.05  /*Injection well Quebrada Hicatea
         1        34        49      0.10  /*Injection well Quebrada Hicatea
         1        34        50      0.05  /*Injection well Quebrada Hicatea
         1        34        51      0.05  /*Injection well Quebrada Hicatea
         1        33        50      0.05  /*Injection well Quebrada Hicatea
         1        33        51      0.05  /*Injection well Quebrada Hicatea
         1        34        34      0.12  /*Injection well Quebrada El Salto
         1        34        35      0.12  /*Injection well Quebrada El Salto
         1        34        36      0.12  /*Injection well Quebrada El Salto
         1        36        37      0.12  /*Injection well Quebrada El Salto
         1        34        40      0.08  /*Injection well Pugnado Adentro
         1        34        41      0.08  /*Injection well Pugnado Adentro
         1        34        42      0.08  /*Injection well Pugnado Adentro
         1        34        43      0.08  /*Injection well Pugnado Adentro
         1        34        44      0.08  /*Injection well Pugnado Adentro
         1        34        45      0.08  /*Injection well Pugnado Adentro
         1        26        31     -1.25  /*Coto Sur 1 (PS)
         1        25        38     -0.00  /*Coto Sur 2 (PS
         1        26        35     -0.71  /*Coto Sur 5 (PS)
         1        26        33     -0.84  /*Coto Sur 6 (PS)
         1        29        24     -0.36  /*Coto Sur 4 (PS)
         1        25        31     -0.00  /*Coto Sur 3 (PS)
         1        26        30     -0.26  /*Roche (Ind)
         1        28        25     -0.41  /*Escal Fullery (PS)
         1        22        28     -0.39  /*Davis & Geck N & S (Ind)
         1        22        30     -1.12  /*Schering Plough (Ind)
         1        24        22     -0.94  /*Oficina PRASA (PS)
         1        23        25     -1.22  /*Cordova Davilla (PS)
         1        25        40     -0.00  /*Pugnado 3 (PS)
         1        20        58     -0.45  /*Vega Baja 1 (PS)
         1        18        52     -0.62  /*Vega Baja 2 (PS)
         1        20        53     -1.80  /*Vega Baja 3 (PS)
         1        20        54     -0.60  /*Vega Baja 4 (PS)
         1        23        52     -0.87  /*Alturas (PS)
         1        21        50     -0.87  /*Algarrobo (PS)
         1        21        47     -0.42  /*Agregado (Mn)
         1        22        42     -0.47  /*Sobrino (PS)
         1        25        51     -0.70  /*Pugnado Afuera 1 (PS)
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
      1        26        50     -0.80  /*Pugnado Afuera 2 (PS)
      1        21        40     -0.20  /*Coto Norte 3 (PS)
      1        21        32     -0.23  /*Atenas (PS)
      1        23        33     -0.11  /*Eaton Labs (Ind)
      1        23        35     -0.11  /*Orto Lab (Ind)
      1        17        22     -0.70  /*Rabanos (PS)
      1        13        21     -0.83  /*Boquillas (PS)
      1        18        20     -0.39  /*Cruz Rosa Rivas (PS)
      1        31        64     -0.19  /*Almirante 2 (PS)
      1        31        66     -0.22  /*Arraiza (PS)
      1        25        63     -0.36  /*Almirante 3 (PS)
      1        21        66     -1.09  /*Monserrate (PS)
      1        26        19     -2.03  /*Manati 1 (PS)
      1        26        18     -1.87  /*Manati 2 (PS)
      1        25        16     -0.00  /*Safety Kleen (Ind)
      1        27        56     -0.25  /*Villa Pinares (PS)
      1        17        70     -0.07  /*Warner Lambert 1 (Ind)
      1        18        70     -0.07  /*Warner Lambert 2 (Ind)
      1        20         1     -0.81  /*Fortuna (PS)
      1        19        70     -0.31  /*Sabana Hoyos 3 (PS)
      1        14        22     -0.11  /*Cubano Jacobo (Irr)
      1        26        33     -0.05  /*Coto Sur Warehouse (Irr)
      1        35        20     -0.08  /*Monserrate Sur (Irr)
      1        22        33     -0.00  /*Coto Norte 1 (PS)
      1        17        73     -0.16  /*Sabana Hoyos 2 (PS)
      1        23        17     -0.02  /*Calaf (Irr)
      1        23        72     -0.99  /*Santa Rosa 2 (PS)
      1        21        39     -0.00  /*Coto Norte 2 (PS)

DRAIN PACKAGE INPUT FILE:

     14        -6
     14
      1        12        17 0.500E+00 2000.E+00 /*Springs Mameyes
      1        12        14 0.500E+00 2000.E+00 /*Tierras Nuevas
      1        12        15 0.500E+00 2000.E+00 /*Tierras Nuevas
      1        13        14 0.800E+00 2000.E+00 /*Tierras Nuevas
      1        15        32 1.500E+00 2000.E+00 /*Laguna South
      1        15        33 1.500E+00 2000.E+00 /*Laguna South
      1        16        34 1.500E+00 2000.E+00 /*Laguna South
      1        15        35 1.500E+00 2000.E+00 /*Laguna South
      1        15        36 1.500E+00 2000.E+00 /*Laguna South
      1        18        53 4.300E+00 2000.E+00 /*Ojo de Agua
      1        18        54 4.300E+00 2000.E+00 /*Ojo de Agua
      1        26         9 5.500E+00 2000.E+00 /*Ojo de Guillo
      1        27         8 5.500E+00 2000.E+00 /*Ojo de Guillo
      1        27         9 5.500E+00 2000.E+00 /*Ojo de Guillo


RIVER PACKAGE INPUT FILE:

    289        -6        /*           RIVERBED   BOTTOM
    289                  /*  STAGE   CONDUCTANCE  ELEV.
      1         8         7 0.500E+00 1.000E-01 -2.000E+0 /*Rio Grande de Manati
      1         8         8 0.500E+00 1.000E-01 -2.000E+0 /*Rio Grande de Manati
      1         9         8 0.500E+00 1.000E-01 -2.000E+0 /*Rio Grande de Manati
      1        10         8 0.500E+00 1.000E-01 -2.000E+0 /*Rio Grande de Manati
      1        11         8 0.500E+00 1.000E-01 -2.000E+0 /*Rio Grande de Manati
      1        12         8 0.500E+00 1.000E-01 -2.000E+0 /*Rio Grande de Manati
      1        13         8 1.500E-01 1.000E-01 -1.000E+0 /*Rio Grande de Manati
      1        14         7 3.500E-01 1.000E-01 -1.000E+0 /*Rio Grande de Manati
      1        15         6 5.500E-01 1.000E-01 -1.000E+0 /*Rio Grande de Manati
      1        16         6 6.000E-01 1.000E-01 -1.000E+0 /*Rio Grande de Manati
```

```
1    16    7 7.000E-01 1.000E-01 -1.000E+0 /*Rio Grande de Manati
1    15    8 1.050E+00 1.000E-01 0.000E+00 /*Rio Grande de Manati
1    15    9 1.170E+00 1.000E-01 0.000E+00 /*Rio Grande de Manati
1    16   10 1.250E+00 1.000E-01 0.000E+00 /*Rio Grande de Manati
1    17    9 1.330E+00 1.000E-01 0.000E+00 /*Rio Grande de Manati
1    18    8 1.440E+00 1.000E-01 0.000E+00 /*Rio Grande de Manati
1    18    7 1.500E+00 1.000E-01 0.000E+00 /*Rio Grande de Manati
1    18    6 1.700E+00 1.000E-01 0.000E+00 /*Rio Grande de Manati
1    19    6 1.800E+00 1.000E-01 0.000E+00 /*Rio Grande de Manati
1    19    5 2.500E+00 1.000E-01 1.000E+00 /*Rio Grande de Manati
1    20    5 2.800E+00 1.000E-01 1.000E+00 /*Rio Grande de Manati
1    20    6 2.900E+00 1.000E-01 1.000E+00 /*Rio Grande de Manati
1    20    7 3.100E+00 1.000E-01 1.000E+00 /*Rio Grande de Manati
1    21    7 3.120E+00 1.000E-01 1.000E+00 /*Rio Grande de Manati
1    21    6 3.140E+00 1.000E-01 1.000E+00 /*Rio Grande de Manati
1    22    6 3.200E+00 3.000E-01 1.000E+00 /*Rio Grande de Manati
1    23    6 3.500E+00 3.000E-01 1.000E+00 /*Rio Grande de Manati
1    23    7 3.630E+00 3.000E-01 1.000E+00 /*Rio Grande de Manati
1    23    8 3.790E+00 3.000E-01 1.000E+00 /*Rio Grande de Manati
1    22    8 3.960E+00 3.000E-01 2.000E+00 /*Rio Grande de Manati
1    21    8 4.050E+00 3.000E-01 2.000E+00 /*Rio Grande de Manati
1    21    9 4.250E+00 3.000E-01 2.000E+00 /*Rio Grande de Manati
1    22    9 4.350E+00 3.000E-01 2.000E+00 /*Rio Grande de Manati
1    23    9 4.500E+00 3.000E-01 2.000E+00 /*Rio Grande de Manati
1    24    9 4.700E+00 3.000E-01 2.000E+00 /*Rio Grande de Manati
1    24   10 4.910E+00 3.000E-01 2.000E+00 /*Rio Grande de Manati
1    24   11 5.000E+00 3.000E-01 3.000E+00 /*Rio Grande de Manati
1    25   11 5.050E+00 3.000E-01 3.000E+00 /*Rio Grande de Manati
1    25   10 5.350E+00 3.000E-01 3.000E+00 /*Rio Grande de Manati
1    26   10 5.800E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    26   11 6.000E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    27   11 6.270E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    27   12 6.430E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    28   12 6.600E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    28   13 6.900E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    27   13 7.100E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    27   14 7.400E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    26   14 7.550E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    26   15 7.650E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    26   16 7.800E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    27   16 8.000E+00 4.000E-01 3.000E+00 /*Rio Grande de Manati
1    28   16 8.500E+00 4.000E-01 4.000E+00 /*Rio Grande de Manati
1    29   16 8.700E+00 4.000E-01 4.000E+00 /*Rio Grande de Manati
1    29   17 9.800E+00 4.000E-01 5.000E+00 /*Rio Grande de Manati
1    30   17 1.080E+01 4.000E-01 6.500E+00 /*Rio Grande de Manati
1    30   18 1.408E+01 4.000E-01 7.500E+00 /*Rio Grande de Manati
1    29   18 1.550E+01 4.000E-01 1.050E+01 /*Rio Grande de Manati
1    28   18 1.780E+01 6.000E-01 1.180E+01 /*Rio Grande de Manati
1    28   19 2.020E+01 6.000E-01 1.200E+01 /*Rio Grande de Manati
1    28   20 2.250E+01 6.000E-01 1.330E+01 /*Rio Grande de Manati
1    28   21 2.500E+01 6.000E-01 1.460E+01 /*Rio Grande de Manati
1    29   21 2.600E+01 6.000E-01 1.540E+01 /*Rio Grande de Manati
1    30   21 2.700E+01 6.000E-01 1.600E+01 /*Rio Grande de Manati
1    31   21 2.750E+01 6.000E-01 1.650E+01 /*Rio Grande de Manati
1    32   21 2.800E+01 6.000E-01 1.800E+01 /*Rio Grande de Manati
1    32   20 2.852E+01 6.000E-01 1.900E+01 /*Rio Grande de Manati
1    32   19 2.900E+01 6.000E-01 2.000E+01 /*Rio Grande de Manati
1    33   19 2.950E+01 6.000E-01 2.200E+01 /*Rio Grande de Manati
1    34   18 3.000E+01 6.000E-01 2.400E+01 /*Rio Grande de Manati
1    35   19 3.050E+01 6.000E-01 2.500E+01 /*Rio Grande de Manati
1    36   19 3.100E+01 6.000E-01 2.800E+01 /*Rio Grande de Manati
1     6   60 0.500E+00 3.000E-02 -9.000E+0 /*Cano Las Pozas
1     7   60 0.500E+00 3.000E-02 -8.500E+0 /*Cano Las Pozas
```

```
1         8        60 5.000E-01 3.000E-02 -6.000E+0 /*Cano Las Pozas
1         8        61 5.000E-01 3.000E-02 -6.000E+0 /*Cano Las Pozas
1         9        60 1.000E+00 3.000E-02 -3.000E+0 /*Cano Las Pozas
1         9        61 1.000E+00 3.000E-02 -3.000E+0 /*Cano Las Pozas
1        10        60 1.500E+00 3.000E-02 -1.000E+0 /*Cano Las Pozas
1        11        60 1.500E+00 3.000E-02 -1.000E+0 /*Cano Las Pozas
1        12        59 1.500E+00 3.000E-02 -1.000E+0 /*Cano Las Pozas
1        13        60 2.000E+00 3.000E-02 -0.500E+0 /*Cano Las Pozas
1        14        60 2.000E+00 3.000E-02 -0.500E+0 /*Cano Las Pozas
1        15        60 2.000E+00 3.000E-02 -0.500E+0 /*Cano Las Pozas
1        16        61 2.500E+00 3.000E-02 -0.000E+0 /*Cano Las Pozas
1        17        61 2.500E+00 3.000E-02 -0.000E+0 /*Cano Las Pozas
1        18        61 2.500E+00 3.000E-02 -0.000E+0 /*Cano Las Pozas
1        13        58 2.000E+00 3.000E-02 -1.000E+0 /*Cano Las Pozas
1        13        57 2.000E+00 3.000E-02 -1.000E+0 /*Cano Las Pozas
1        14        57 2.000E+00 3.000E-02 -1.000E+0 /*Cano Las Pozas
1        15        57 2.500E+00 3.000E-02 -1.000E+0 /*Cano Las Pozas
1         6        59 5.000E-01 3.000E-02 -6.000E+0 /*Cano Cabo Caribe
1         6        58 5.000E-01 3.000E-02 -6.000E+0 /*Cano Cabo Caribe
1         7        58 1.000E+00 3.000E-02 -4.000E+0 /*Cano Cabo Caribe
1         7        57 1.000E+00 3.000E-02 -4.000E+0 /*Cano Cabo Caribe
1         7        56 1.000E+00 3.000E-02 -4.000E+0 /*Cano Cabo Caribe
1         8        55 1.500E+00 3.000E-02 -2.000E+0 /*Cano Cabo Caribe
1         9        55 1.500E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        10        55 1.500E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        10        54 1.600E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        11        54 1.700E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        11        53 1.600E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        10        52 2.000E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        10        51 1.700E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        11        51 2.000E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        12        51 2.000E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        12        52 1.800E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        13        51 2.000E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        13        52 1.900E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        14        51 2.000E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        14        50 2.000E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        14        52 2.000E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        14        49 2.000E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        13        49 1.800E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1        11        49 1.900E+00 3.000E-01 -2.000E+0 /*Cano Cabo Caribe
1         9        37 0.000E+00 3.000E-01 -2.000E+0 /*Laguna Tortuguero Outlet
1        10        38 0.300E+00 3.000E-01 -2.000E+0 /*Laguna Tortuguero Outlet
1        11        38 0.600E+00 3.000E-01 -2.000E+0 /*Laguna Tortuguero Outlet
1        12        31 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        12        32 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        30 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        31 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        32 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        33 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        37 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        38 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        39 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        40 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        41 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        42 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        43 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        44 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        13        45 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        14        36 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        14        37 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        14        39 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
1        14        40 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
         1         14         41 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
         1         14         42 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
         1         14         43 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
         1         14         44 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
         1         15         43 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
         1         15         44 0.900E+00 0.120E+00 -2.000E+0 /*Laguna Tortuguero
         1          5         61 0.500E+00 1.000E-01 -9.500E+0 /*Rio Cibuco
         1          6         61 0.500E+00 1.000E-01 -9.000E+0 /*Rio Cibuco
         1          6         62 0.500E+00 1.000E-01 -8.500E+0 /*Rio Cibuco
         1          7         62 0.500E+00 1.000E-01 -8.000E+0 /*Rio Cibuco
         1          8         63 0.500E+00 1.000E-01 -7.500E+0 /*Rio Cibuco
         1          8         64 0.500E+00 1.000E-01 -7.000E+0 /*Rio Cibuco
         1          8         65 0.500E+00 1.000E-01 -6.500E+0 /*Rio Cibuco
         1          8         66 1.000E+00 1.000E-01 -5.000E+0 /*Rio Cibuco
         1          8         67 1.000E+00 1.000E-01 -4.000E+0 /*Rio Cibuco
         1          9         68 1.500E+00 1.000E-01 -3.000E+0 /*Rio Cibuco
         1         10         68 1.500E+00 1.000E-01 -2.500E+0 /*Rio Cibuco
         1         11         68 2.000E+00 1.000E-01 -2.000E+0 /*Rio Cibuco
         1         11         67 2.500E+00 1.000E-01 -1.500E+0 /*Rio Cibuco
         1         12         67 2.500E+00 1.000E-01 -1.000E+0 /*Rio Cibuco
         1         12         66 2.500E+00 1.000E-01 -5.000E-1 /*Rio Cibuco
         1         13         66 2.500E+00 1.000E-01 0.000E+00 /*Rio Cibuco
         1         14         66 3.000E+00 5.000E-01 5.000E-01 /*Rio Cibuco
         1         14         65 3.000E+00 5.000E-01 8.000E-01 /*Rio Cibuco
         1         15         65 3.500E+00 5.000E-02 1.000E+00 /*Rio Cibuco
         1         15         64 4.500E+00 5.000E-02 1.500E+00 /*Rio Cibuco
         1         16         64 5.000E+00 5.000E-02 2.000E+00 /*Rio Cibuco
         1         16         63 5.500E+00 5.000E-02 2.500E+00 /*Rio Cibuco
         1         17         63 6.000E+00 5.000E-02 4.000E+00 /*Rio Cibuco
         1         17         62 9.000E+00 5.000E-02 6.500E+00 /*Rio Cibuco
         1         18         62 1.100E+01 5.000E-02 8.000E+00 /*Rio Cibuco
         1         19         62 1.250E+01 1.100E-01 9.000E+00 /*Rio Cibuco
         1         19         63 1.300E+01 1.100E-01 9.000E+00 /*Rio Cibuco
         1         20         64 1.350E+01 1.100E-01 9.000E+00 /*Rio Cibuco
         1         20         65 1.400E+01 1.100E-01 1.000E+01 /*Rio Cibuco
         1         21         65 1.450E+01 1.100E-01 1.100E+01 /*Rio Cibuco
         1         21         66 1.500E+01 1.100E-01 1.300E+01 /*Rio Cibuco
         1         22         66 1.650E+01 1.100E-01 1.400E+01 /*Rio Cibuco
         1         23         67 1.800E+01 1.100E-01 1.550E+01 /*Rio Cibuco
         1         24         67 1.900E+01 1.100E-01 1.650E+01 /*Rio Cibuco
         1         25         67 2.000E+01 1.100E-01 1.750E+01 /*Rio Cibuco
         1         25         68 2.100E+01 1.100E-01 1.850E+01 /*Rio Cibuco
         1         25         69 2.250E+01 1.100E-01 2.000E+01 /*Rio Cibuco
         1         25         70 2.350E+01 3.000E-02 2.150E+01 /*Rio Cibuco
         1         25         71 2.400E+01 3.000E-02 2.200E+01 /*Rio Cibuco
         1         25         72 2.500E+01 3.000E-02 2.250E+01 /*Rio Cibuco
         1         26         72 2.800E+01 3.000E-02 2.300E+01 /*Rio Cibuco
         1         27         72 3.000E+01 3.000E-02 2.600E+01 /*Rio Cibuco
         1         28         72 3.050E+01 3.000E-02 2.850E+01 /*Rio Cibuco
         1         28         73 3.300E+01 3.000E-02 3.100E+01 /*Rio Cibuco
         1         21         65 1.400E+01 4.000E-02 1.200E+01 /*Rio Indio
         1         22         65 1.450E+01 4.000E-02 1.150E+01 /*Rio Indio
         1         22         64 1.500E+01 4.000E-02 1.100E+01 /*Rio Indio
         1         22         63 1.600E+01 4.000E-02 1.400E+01 /*Rio Indio
         1         23         63 1.700E+01 4.000E-02 1.500E+01 /*Rio Indio
         1         23         62 1.800E+01 4.000E-02 1.600E+01 /*Rio Indio
         1         23         61 1.950E+01 4.000E-02 1.750E+01 /*Rio Indio
         1         24         61 2.100E+01 4.000E-02 1.900E+01 /*Rio Indio
         1         24         60 2.300E+01 4.000E-02 2.100E+01 /*Rio Indio
         1         25         60 2.450E+01 4.000E-02 2.250E+01 /*Rio Indio
         1         26         60 2.600E+01 4.000E-02 2.450E+01 /*Rio Indio
         1         27         60 2.700E+01 4.000E-02 2.500E+01 /*Rio Indio
         1         27         61 2.800E+01 4.000E-02 2.600E+01 /*Rio Indio
```

Appendix 1. Input files for the Manatí-Vega Baja model of the upper aquifer—Continued.

```
         1        27        62 3.000E+01 4.000E-02 2.800E+01 /*Rio Indio
         1        28        62 3.200E+01 4.000E-02 3.000E+01 /*Rio Indio
         1        29        61 3.300E+01 4.000E-02 3.100E+01 /*Rio Indio
         1        29        62 3.400E+01 4.000E-02 3.200E+01 /*Rio Indio
         1        30        62 3.500E+01 4.000E-02 3.300E+01 /*Rio Indio
         1        30        61 3.600E+01 4.000E-02 3.400E+01 /*Rio Indio
         1        30        60 3.700E+01 4.000E-02 3.500E+01 /*Rio Indio
         1        31        60 3.800E+01 4.000E-02 3.600E+01 /*Rio Indio
         1        31        59 3.900E+01 4.000E-02 3.700E+01 /*Rio Indio
         1        32        59 4.000E+01 4.000E-02 3.800E+01 /*Rio Indio
         1        32        58 4.100E+01 4.000E-02 3.900E+01 /*Rio Indio
         1        33        57 4.200E+01 4.000E-02 4.000E+01 /*Rio Indio
         1        34        57 4.300E+01 4.000E-02 4.100E+01 /*Rio Indio
         1        34        56 4.550E+01 4.000E-02 4.400E+01 /*Rio Indio
         1        35        56 4.800E+01 4.000E-02 4.650E+01 /*Rio Indio
         1        35        55 4.900E+01 4.000E-02 4.750E+01 /*Rio Indio
         1        36        55 5.000E+01 4.000E-02 4.850E+01 /*Rio Indio
         1         3         1 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         3         2 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         4         3 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         5         4 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         5         5 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         6         6 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         6         7 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         5         8 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         5         9 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         5        10 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         5        11 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         6        12 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         6        13 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        14 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        15 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        16 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        17 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        18 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        19 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        20 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        21 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         7        22 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         8        23 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         8        24 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         8        25 0.000E+00 1.000E+02 -2.000E+0 /*Atlantic Ocean
         1         8        26 0.000E+00 1.000E+02 -2.000E+0 /*Atlantic Ocean
         1         8        27 0.000E+00 1.000E+02 -2.000E+0 /*Atlantic Ocean
         1         8        28 0.000E+00 1.000E+02 -2.000E+0 /*Atlantic Ocean
         1         8        29 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         8        30 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         8        31 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         7        32 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         7        33 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         6        34 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         5        35 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         4        36 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        37 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        38 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        39 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        40 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
```

```
         1         3        41 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        42 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        43 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        44 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        45 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        46 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        47 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        48 0.000E+00 3.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        49 0.000E+00 1.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        50 0.000E+00 1.000E+02 -2.000E+0 /*Atlantic Ocean
         1         3        51 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         3        52 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         3        53 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         2        54 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         2        55 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         3        56 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         3        57 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         4        58 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         4        59 0.000E+00 1.000E-01 -2.000E+0 /*Atlantic Ocean
         1         4        60 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         4        61 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         4        62 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         4        63 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         4        64 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         5        65 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         5        66 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         4        67 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         4        68 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         4        69 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         5        70 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         5        71 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         5        72 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
         1         6        73 0.000E+00 3.000E+01 -2.000E+0 /*Atlantic Ocean
```

```
STRONGLY IMPLICIT PROCEDURE INPUT FILE:

       100         5
       1.0      0.01         1
```

```
OUTPUT CONTROL INPUT FILE:

         4         0        30         0  IHEDFM,IDDNFM,IHEDUN,IDDNUN
         1         1         1         1  1,1,IBUDFL,ICBCFL: PER.   1  STEP   1
         1         0         1         0  Hdpr,Ddpr,Hdsv,Ddsv
```

Appendix 2a. Summary of sensitivity of ground-water recharge.

[Outlined values indicate final calibration results for 1995 hydrologic conditions. Results consist of the difference between observed and computed head, the percentage difference within a specified range, and the volumetric budget terms in cubic feet per second. Multiplier applied to the calibrated rate values are underlined. Refer to fig. 16 for control-cell location.]

DIFFERENCE BETWEEN OBSERVED AND COMPUTED HEAD, IN FEET

	0.25	0.50	0.75	1.00	1.25	1.50	ROW	COLUMN	WELL NAME
	-2	-1.66	-1.46	-1.31	-1.16	-1.01	9	42	Martinez
	-0.62	-0.14	0.19	0.42	0.64	0.86	12	48	Cerro Guarico
	-0.86	-0.64	-0.43	-0.22	-0.01	0.2	13	2	Plazuela 2
	-5.6	-3.64	-2.45	-1.43	-0.41	0.6	13	21	Boquillas
	-1.2	0	0.61	0.96	1.26	1.54	14	62	Rice Program 5
	-2.53	-0.44	0.89	2.03	3.17	4.3	15	28	Alvarez
	-3.92	-1.9	-0.46	0.63	1.68	2.72	17	46	Tortuguero TW-3
	-2.54	-0.22	1.02	1.7	2.3	2.88	17	57	China Caribe
	-5.4	-3.05	-1.34	0.24	1.82	3.39	18	20	Cruz Rosa Rivas
	-4	-1.34	-0.02	0	0	0	18	53	Ojo de Agua Spring
	-4.51	-1.82	0.16	1.97	3.78	5.57	19	26	Dupont 3 (upper)
	-2.43	-1.97	-1.51	-1.05	-0.59	-0.14	20	4	Barceloneta-Imbery
	-6.28	-2.98	-0.89	0.39	1.57	2.73	20	53	Vega Baja 3
	-2.85	-1.33	-0.14	0.98	2.11	3.23	22	16	Manati - Los Nachos
	-7.15	-3.97	-1.5	0.79	3.08	5.35	22	28	Davis & Geck N
	-1.75	-1.6	-1.45	-1.3	-1.15	-1.01	23	5	Canning 1
	-8.68	-4.94	-2.03	0.67	3.37	6.05	23	33	Eaton Labs
	-9.18	-5.44	-2.53	0.17	2.87	5.55	23	33	Eaton Labs
	-9.24	-4.91	-1.37	1.82	4.95	8.08	23	41	Palo Alto 2
	-4.36	-0.39	2.34	4.29	6.05	7.76	23	56	Rosario 2
	-8.97	-5.07	-2.52	-0.75	0.74	2.15	23	60	La Trocha
	-8.73	-4.82	-1.66	1.32	4.29	7.25	24	31	Campo Alegre
	-7.42	-1.32	3.97	8.96	13.91	18.85	25	38	Coto Sur 2
	-6.4	-0.29	5	9.92	14.79	19.65	25	40	Pugnado 3
	-13.38	-8.76	-5.69	-3.59	-1.93	-0.4	25	63	Almirante 3
	0.32	0.48	0.6	0.72	0.84	0.96	25	15	Manatí 3
	0.36	1.49	2.43	3.32	4.21	5.09	26	19	Manatí 1
	-8.44	-1.59	4.44	10.2	15.92	21.64	26	37	Coto Sur 7
	-13.89	-8.8	-4.69	-1.26	2.03	5.3	26	47	Palo Alto 3
	-18.25	-13.43	-9.68	-6.68	-3.83	-1.02	26	50	Pugnado Afuera 2
	-6.02	1.98	9.14	15.91	22.62	29.31	27	40	Palo Alto 1
	-15.02	-9.84	-5.95	-3.06	-0.57	1.84	27	57	Pantojas
	-24.95	-19.22	-14.09	-9.12	-4.15	0.79	29	29	USGS Hill 1
	-20.85	-13.09	-5.95	1.02	7.98	14.92	30	30	USGS Hill 2
	-17.4	-7.08	1.55	8.15	13.53	18.62	31	64	Almirante 2
	-78.27	-53.43	-29.5	-6.07	17.25	40.56	34	42	Perica
	-77.22	-49.84	-23.45	2.29	27.86	53.41	34	45	Martinez
PERCENT DIFFERENCE:									
1 FEET	10	21	40	35	21	21			
2 FEET	18	51	54	62	40	35			
5 FEET	40	70	75	78	75	54			
10 FEET	75	86	89	94	81	78			
18 FEET	86	91	94	100	94	81			

VOLUMETRIC BUDGET TERMS, IN CUBIC FEET PER SECOND

	0.25	0.50	0.75	1.00	1.25	1.50
IN:						
STORAGE =						
CONSTANT HEAD =	0.00	0.00	0.00	0.00	0.00	0.00
WELLS =	1.61	1.61	1.61	1.61	1.61	1.61
DRAINS =	0.00	0.00	0.00	0.00	0.00	0.00
RIVER LEAKAGE =	19.99	15.9	13.48	11.07	8.88	7.08
RECHARGE =	8.98	17.97	26.95	35.93	44.92	53.9
TOTAL IN =	30.58	35.48	42.04	48.61	55.41	62.59
OUT:						
STORAGE =						
CONSTANT HEAD =	0.00	0.00	0.00	0.00	0.00	0.00
WELLS =	26.35	26.35	26.35	26.35	26.35	26.35
DRAINS =	0.30	1.01	3.77	7.32	10.76	14.18
RIVER LEAKAGE =	3.92	8.12	11.92	14.95	18.30	22.06
RECHARGE =	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL OUT =	30.57	35.48	42.04	48.62	55.41	62.59

Appendix 2b. Summary of sensitivity analysis for simulated injection and pumping rates at wells.

DIFFERENCE BETWEEN OBSERVED AND COMPUTED HEAD, IN FEET

	0.25	0.50	0.75	1.00	1.25	1.50	ROW	COLUMN	WELL NAME
	-1.06	-1.14	-1.22	-1.31	-1.39	-1.48	9	42	Martinez
	0.81	0.68	0.55	0.42	0.29	0.14	12	48	Cerro Guarico
	0.35	0.16	-0.03	-0.22	-0.41	-0.6	13	2	Plazuela 2
	3.49	1.85	0.21	-1.43	-3.07	-4.94	13	21	Boquillas
	1.56	1.37	1.17	0.96	0.75	0.49	14	62	Rice Program 5
	5.69	4.47	3.25	2.03	0.81	-0.54	15	28	Alvarez
	2.39	1.81	1.22	0.63	0.04	-0.63	17	46	Tortuguero TW-3
	2.84	2.46	2.09	1.7	1.3	0.82	17	57	China Caribe
	6.77	4.59	2.42	0.24	-1.93	-4.26	18	20	Cruz Rosa Rivas
	0	0	0	0	0	-0.49	18	53	Ojo de Agua Spring
	7.89	5.92	3.94	1.97	-0.01	-2.09	19	26	Dupont 3 (upper)
	-0.13	-0.44	-0.74	-1.05	-1.36	-1.67	20	4	Barceloneta-Imbery
	3.65	2.57	1.48	0.39	-0.71	-2	20	53	Vega Baja 3
	4.85	3.56	2.27	0.98	-0.31	-1.66	22	16	Manati - Los Nachos
	8.34	5.82	3.31	0.79	-1.73	-4.34	22	28	Davis & Geck N
	-1.17	-1.22	-1.26	-1.3	-1.34	-1.39	23	5	Canning 1
	7.83	5.44	3.06	0.67	-1.71	-4.18	23	33	Eaton Labs
	7.33	4.94	2.56	0.17	-2.21	-4.68	23	33	Eaton Labs
	5.42	4.22	3.02	1.82	0.61	-0.68	23	41	Palo Alto 2
	7	6.11	5.21	4.29	3.36	2.29	23	56	Rosario 2
	1.29	0.64	-0.04	-0.75	-1.48	-2.35	23	60	La Trocha
	9.93	7.06	4.19	1.32	-1.55	-4.51	24	31	Campo Alegre
	14.25	12.49	10.72	8.96	7.19	5.34	25	38	Coto Sur 2
	13.89	12.57	11.24	9.92	8.59	7.17	25	40	Pugnado 3
	-1.12	-1.91	-2.73	-3.59	-4.49	-5.56	25	63	Almirante 3
	1.25	1.08	0.9	0.72	0.54	0.36	25	15	Manatí 3
	11.5	8.77	6.05	3.32	0.59	-2.17	26	19	Manatí 1
	16.99	14.73	12.46	10.2	7.93	5.58	26	37	Coto Sur 7
	1.96	0.9	-0.18	-1.26	-2.35	-3.58	26	47	Palo Alto 3
	-2.52	-3.9	-5.28	-6.68	-8.08	-9.63	26	50	Pugnado Afuera 2
	19.51	18.31	17.11	15.91	14.7	13.4	27	40	Palo Alto 1
	-0.19	-1.13	-2.09	-3.06	-4.06	-5.2	27	57	Pantojas
	-0.78	-3.56	-6.34	-9.12	-11.9	-14.75	29	29	USGS Hill 1
	8.47	5.99	3.51	1.02	-1.46	-4.02	30	30	USGS Hill 2
	14.39	12.37	10.28	8.15	5.97	3.59	31	64	Almirante 2
	-108.57	-74.4	-40.23	-6.07	28.09	62.14	34	42	Perica
	-113.93	-75.19	-36.45	2.29	41.01	79.61	34	45	Martinez
PERCENT DIFFERENCE:									
1 FEET	16	16	21	35	32	24			
2 FEET	35	37	35	62	59	35			
5 FEET	51	62	70	78	75	72			
10 FEET	78	81	81	94	89	89			
18 FEET	91	91	94	100	94	94			

VOLUMETRIC BUDGET TERMS, IN CUBIC FEET PER SECOND

	0.25	0.50	0.75	1.00	1.25	1.50
IN:						
STORAGE =						
CONSTANT HEAD =	0.00	0.00	0.00	0.00	0.00	0.00
WELLS =	0.4025	0.805	1.2075	1.61	2.0125	2.415
DRAINS =	0.00	0.00	0.00	0.00	0.00	0.00
RIVER LEAKAGE =	5.9896	7.6156	9.296	11.07	13.10	15.2376
RECHARGE =	35.933	35.933	35.933	35.93	35.933	35.933
TOTAL IN =	42.3251	44.3536	46.4365	48.61	51.0405	53.5856
OUT:						
STORAGE =						
CONSTANT HEAD =	0.00	0.00	0.00	0.00	0.00	0.00
WELLS =	6.5875	13.175	19.7625	26.35	32.9375	39.525
DRAINS =	14.56	12.1509	9.7381	7.32	4.8888	2.7263
RIVER LEAKAGE =	21.18	19.0282	16.9365	14.95	13.2137	11.3293
RECHARGE =	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL OUT =	42.3255	44.35	46.4371	48.62	51.04	53.5806

Appendix 2c. Summary of sensitivity analysis of aquifer transmissivity.

DIFFERENCE BETWEEN OBSERVED AND COMPUTED HEAD, IN FEET

	0.25	0.50	0.75	1.00	1.25	1.50	ROW	COLUMN	WELL NAME
	-1.58	-1.47	-1.38	-1.31	-1.24	-1.19	9	42	Martinez
	0.47	0.39	0.4	0.42	0.44	0.46	12	48	Cerro Guarico
	-0.47	-0.34	-0.27	-0.22	-0.17	-0.12	13	2	Plazuela 2
	-8.99	-3.85	-2.23	-1.43	-0.96	-0.65	13	21	Boquillas
	-0.16	0.48	0.79	0.96	1.03	1	14	62	Rice Program 5
	1.03	1.73	1.93	2.03	2.08	2.11	15	28	Alvarez
	4.42	1.96	1.09	0.63	0.33	0.09	17	46	Tortuguero TW-3
	2.46	2.12	1.88	1.7	1.51	1.3	17	57	China Caribe
	-6.67	-1.97	-0.48	0.24	0.66	0.93	18	20	Cruz Rosa Rivas
	0	0	0	0	0	0	18	53	Ojo de Agua Spring
	0.21	1.45	1.81	1.97	2.04	2.08	19	26	Dupont 3 (upper)
	-0.3	-0.83	-0.99	-1.05	-1.08	-1.09	20	4	Barceloneta-Imbery
	0.16	0.56	0.49	0.39	0.23	0.05	20	53	Vega Baja 3
	-0.41	0.56	0.85	0.98	1.05	1.09	22	16	Manati - Los Nachos
	-1.68	0.05	0.56	0.79	0.9	0.95	22	28	Davis & Geck N
	-1.33	-1.33	-1.32	-1.3	-1.28	-1.27	23	5	Canning 1
	4.32	1.95	1.11	0.67	0.39	0.18	23	33	Eaton Labs
	3.82	1.45	0.61	0.17	-0.11	-0.32	23	33	Eaton Labs
	23.77	9.25	4.31	1.82	0.27	-0.8	23	41	Palo Alto 2
	11.96	7.48	5.48	4.29	3.37	2.59	23	56	Rosario 2
	5.32	2.44	0.53	-0.75	-1.82	-2.79	23	60	La Trocha
	2.69	1.86	1.52	1.32	1.18	1.06	24	31	Campo Alegre
	46.49	21.57	13.17	8.96	6.39	4.64	25	38	Coto Sur 2
	51.45	23.9	14.59	9.92	7.06	5.1	25	40	Pugnado 3
	1.58	-0.38	-2.19	-3.59	-4.91	-6.2	25	63	Almirante 3
	0.56	0.6	0.66	0.72	0.78	0.84	25	15	Manatí 3
	-17.18	-3.39	1.13	3.32	4.59	5.4	26	19	Manatí 1
	51.15	23.96	14.79	10.2	7.4	5.5	26	37	Coto Sur 7
	23.47	7.31	1.66	-1.26	-3.15	-4.53	26	47	Palo Alto 3
	8.73	-1.14	-4.75	-6.68	-8	-9.02	26	50	Pugnado Afuera 2
	80.99	37.77	23.21	15.91	11.46	8.43	27	40	Palo Alto 1
	11.29	2.81	-0.88	-3.06	-4.79	-6.28	27	57	Pantojas
	17.54	-0.1	-6.09	-9.12	-10.97	-12.24	29	29	USGS Hill 1
	55.11	19.18	7.09	1.02	-2.66	-5.15	30	30	USGS Hill 2
	38.62	20.13	12.75	8.15	4.09	0.33	31	64	Almirante 2
	683.25	224.08	70.48	-6.07	-52.13	-83.03	34	42	Perica
	772.98	259.68	87.91	2.29	-49.28	-83.91	34	45	Martinez
PERCENT DIFFERENCE:									
1 FEET	24	29	35	35	32	45			
2 FEET	37	56	62	62	54	62			
5 FEET	51	70	72	78	78	72			
10 FEET	62	78	81	94	89	91			
18 FEET	72	78	91	100	94	94			

VOLUMETRIC BUDGET TERMS, IN CUBIC FEET PER SECOND

	0.25	0.50	0.75	1.00	1.25	1.50
IN:						
STORAGE =						
CONSTANT HEAD =	0.00	0.00	0.00	0.00	0.00	0.00
WELLS =	1.61	1.61	1.61	1.61	1.61	1.61
DRAINS =	0.00	0.00	0.00	0.00	0.00	0.00
RIVER LEAKAGE =	4.57	6.47	8.68	11.07	13.40	15.34
RECHARGE =	35.93	35.93	35.93	35.93	35.93	35.93
TOTAL IN =	42.11	44.01	46.22	48.61	50.94	52.88
OUT:						
STORAGE =						
CONSTANT HEAD =	0.00	0.00	0.00	0.00	0.00	0.00
WELLS =	26.35	26.35	26.35	26.35	26.35	26.35
DRAINS =	4.10	5.27	6.33	7.32	8.17	8.89
RIVER LEAKAGE =	11.66	12.38	13.54	14.95	16.42	17.64
RECHARGE =	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL OUT =	42.11	44.00	46.22	48.62	50.94	52.88

Appendix 2d. Summary of sensitivity of riverbed conductance.

DIFFERENCE BETWEEN OBSERVED AND COMPUTED HEAD, IN FEET

	0.25	0.50	0.75	1.00	1.25	1.50	ROW	COLUMN	WELL NAME
	-0.25	-0.85	-1.14	-1.31	-1.42	-1.49	9	42	Martinez
	1.42	0.83	0.57	0.42	0.32	0.25	12	48	Cerro Guarico
	0.45	0.05	-0.12	-0.22	-0.28	-0.32	13	2	Plazuela 2
	-1.67	-1.52	-1.46	-1.43	-1.41	-1.4	13	21	Boquillas
	2.06	1.53	1.21	0.96	0.76	0.58	14	62	Rice Program 5
	1.81	1.95	2.01	2.03	2.04	2.05	15	28	Alvarez
	1.42	0.99	0.77	0.63	0.54	0.46	17	46	Tortuguero TW-3
	1.97	1.83	1.76	1.7	1.65	1.59	17	57	China Caribe
	-0.3	0.03	0.17	0.24	0.29	0.33	18	20	Cruz Rosa Rivas
	0	0	0	0	0	0	18	53	Ojo de Agua Spring
	1.42	1.75	1.89	1.97	2.02	2.05	19	26	Dupont 3 (upper)
	-0.22	-0.69	-0.92	-1.05	-1.14	-1.21	20	4	Barceloneta-Imbery
	0.38	0.36	0.37	0.39	0.4	0.41	20	53	Vega Baja 3
	0.39	0.74	0.9	0.98	1.04	1.08	22	16	Manati - Los Nachos
	0.12	0.52	0.69	0.79	0.85	0.89	22	28	Davis & Geck N
	-0.34	-0.89	-1.15	-1.3	-1.4	-1.48	23	5	Canning 1
	0.36	0.56	0.63	0.67	0.7	0.72	23	33	Eaton Labs
	-0.14	0.06	0.13	0.17	0.2	0.22	23	33	Eaton Labs
	2.16	1.97	1.88	1.82	1.77	1.74	23	41	Palo Alto 2
	3.84	4.02	4.18	4.29	4.39	4.47	23	56	Rosario 2
	-1.91	-1.42	-1.03	-0.75	-0.51	-0.32	23	60	La Trocha
	0.75	1.09	1.24	1.32	1.37	1.41	24	31	Campo Alegre
	8.99	8.98	8.97	8.96	8.95	8.94	25	38	Coto Sur 2
	10.08	9.99	9.95	9.92	9.9	9.88	25	40	Pugnado 3
	-5.6	-4.7	-4.04	-3.59	-3.24	-2.96	25	63	Almirante 3
	0.69	0.73	0.73	0.72	0.72	0.71	25	15	Manatí 3
	1.43	2.54	3.03	3.32	3.5	3.63	26	19	Manatí 1
	10.1	10.17	10.19	10.2	10.2	10.2	26	37	Coto Sur 7
	-1.22	-1.27	-1.27	-1.26	-1.25	-1.24	26	47	Palo Alto 3
	-6.76	-6.76	-6.71	-6.68	-6.64	-6.62	26	50	Pugnado Afuera 2
	15.96	15.93	15.92	15.91	15.9	15.89	27	40	Palo Alto 1
	-4.09	-3.65	-3.31	-3.06	-2.86	-2.69	27	57	Pantojas
	-10.1	-9.52	-9.26	-9.12	-9.02	-8.96	29	29	USGS Hill 1
	0.14	0.67	0.9	1.02	1.11	1.16	30	30	USGS Hill 2
	4.8	6.42	7.49	8.15	8.6	8.94	31	64	Almirante 2
	-6.15	-6.12	-6.09	-6.07	-6.05	-6.04	34	42	Perica
	2.21	2.22	2.26	2.29	2.31	2.33	34	45	Martinez
PERCENT DIFFERENCE:									
1 FEET	37	40	35	35	32	32			
2 FEET	62	64	62	62	59	59			
5 FEET	78	78	78	78	78	78			
10 FEET	89	94	94	94	94	94			
18 FEET	100	100	100	100	100	100			
IN:									
STORAGE =									
CONSTANT HEAD =	0.00	0.00	0.00	0.00	0.00	0.00			
WELLS =	1.61	1.61	1.61	1.61	1.61	1.61			
DRAINS =	0.00	0.00	0.00	0.00	0.00	0.00			
RIVER LEAKAGE =	6.68	8.84	10.16	11.07	11.81	12.39			
RECHARGE =	35.93	35.93	35.93	35.93	35.93	35.93			
TOTAL IN =	44.22	46.38	47.7	48.61	49.35	49.93			
OUT:									
STORAGE =									
CONSTANT HEAD =	0.00	0.00	0.00	0.00	0.00	0.00			
WELLS =	26.35	26.35	26.35	26.35	26.35	26.35			
DRAINS =	8.40	7.81	7.51	7.32	7.18	7.07			
RIVER LEAKAGE =	9.47	12.23	13.84	14.95	15.82	16.52			
RECHARGE =	0.00	0.00	0.00	0.00	0.00	0.00			
TOTAL OUT =	44.22	46.39	47.7	48.62	49.35	49.94			

VOLUMETRIC BUDGET TERMS, IN CUBIC FEET PER SECOND